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Proceedings of the

FORT UNION COAL FIELD SYMPOSIUM

Volume 2

AQUATIC ECOSYSTEMS SECTION

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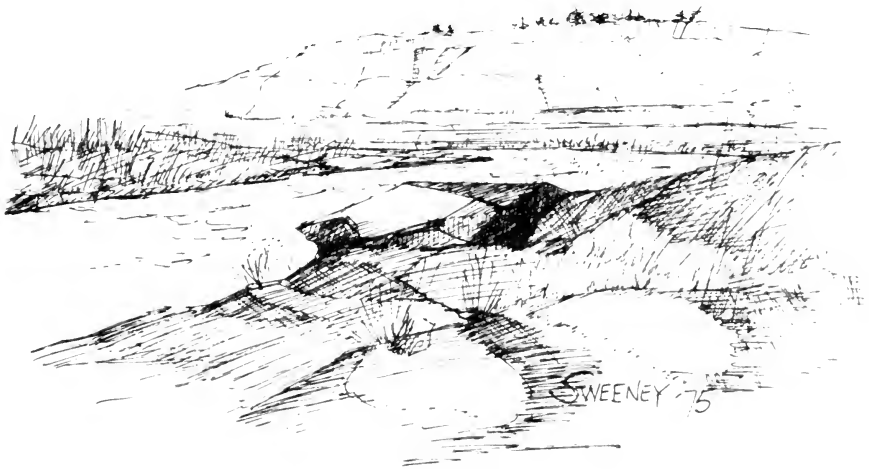
at Eastern Montana College

Billings, Montana April 25, 26 1975



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VOLUME 2

- papers of the AQUATIC ECOSYSTEMS SECTION

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- Order information.
- Acknowledgements.

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Billings, Montana

PRELIMINARY FISHERY INVESTIGATIONS ON THE LOWER YELLOWSTONE RIVER

Larry G. Peterman and Michael H. Haddix*

INTRODUCTION

The major portion of this nation's undeveloped coal reserves lies in the northern Great Plains. The Fort Union coal formation underlies much of eastern Montana and significant portions of Wyoming and North Dakota. In Montana, this formation contains an estimated 43 billion tons of economically strippable coal (8). An additional 115 billion tons are minable by underground methods (10). In light of the current energy crisis, the lack of a serious energy conservation approach, and President Ford's recent State of the Union address to Congress calling for the establishment of 250 major new coal mines, 150 major coal-fired power plants, and 20 major new synthetic fuel plants by 1985, it becomes obvious that the fish and wildlife resources of this region will be subject to massive disturbance.

It is apparent that exploitation of eastern Montana coal can have far reaching effects upon the Yellowstone and it's tributaries. The conversion of coal to more usable forms of energy requires significant quantities of water. The development of coal resources at the mine sites for electric power generation or synthetic gas production may require diversion of water from the Yellowstone River and/or its tributaries and conveyance by aqueducts to the mine sites. Withdrawal of water from the Yellowstone or its tributaries may require storage and diversion structures affecting the present flow regimen and associated aquatic communities. Basic data on the life history and distribution of important game, non-game and forage species of fish in the lower Yellowstone sufficient for complete analysis of the environmental impacts of these diversions and structures are lacking. This study was initiated in April of 1974 to provide such data. The primary source of funding for this project is the Bureau of Reclamation with supplemental monies coming from the Old West Regional Commission, Montana Department of Fish and Game and private industry. In addition to data gathering, this project provides coordination for other aquatic studies on the main stem of the Yellowstone.

The objective of this project is to collect basic inventory and life history data to develop better understandings of existing fish populations and habitats needed to sustain the species present. This information will be used for making decisions on water use and recommendations on diversion points, and for accurate preparation of environmental impact statements.

DESCRIPTION OF YELLOWSTONE RIVER

The study area encompasses the Yellowstone River from the mouth of the Bighorn River to its confluence with the Missouri

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River and is commonly referred to as the lower Yellowstone. The characteristics of the entire river are briefly described to place the lower river in the perspective of the entire system.

The Yellowstone River is free-flowing over its entire length, making it unique among the large rivers of the Continental United States. The Yellowstone originates in the northwest corner of Wyoming, and flows northeasterly through Montana before joining the Missouri River near Cartwright, North Dakota. It has a total drainage area of approximately 70,400 square miles, 35,900 of which lie in Montana. Its length, from its headwaters in Wyoming to its confluence with the Missouri River in North Dakota, is approximately 678 miles, 550 of which are in Montana. Major tributaries entering the Yellowstone in Yellowstone Park include the Gardner and Lamar Rivers. In Montana, the only major south-flowing tributary to the Yellowstone is the Shields River near Livingston. Major north-flowing tributaries to the Yellowstone in Montana include the Boulder, Stillwater, Clarks Fork of the Yellowstone, Bighorn, Tongue, and Powder Rivers (Figure 1).

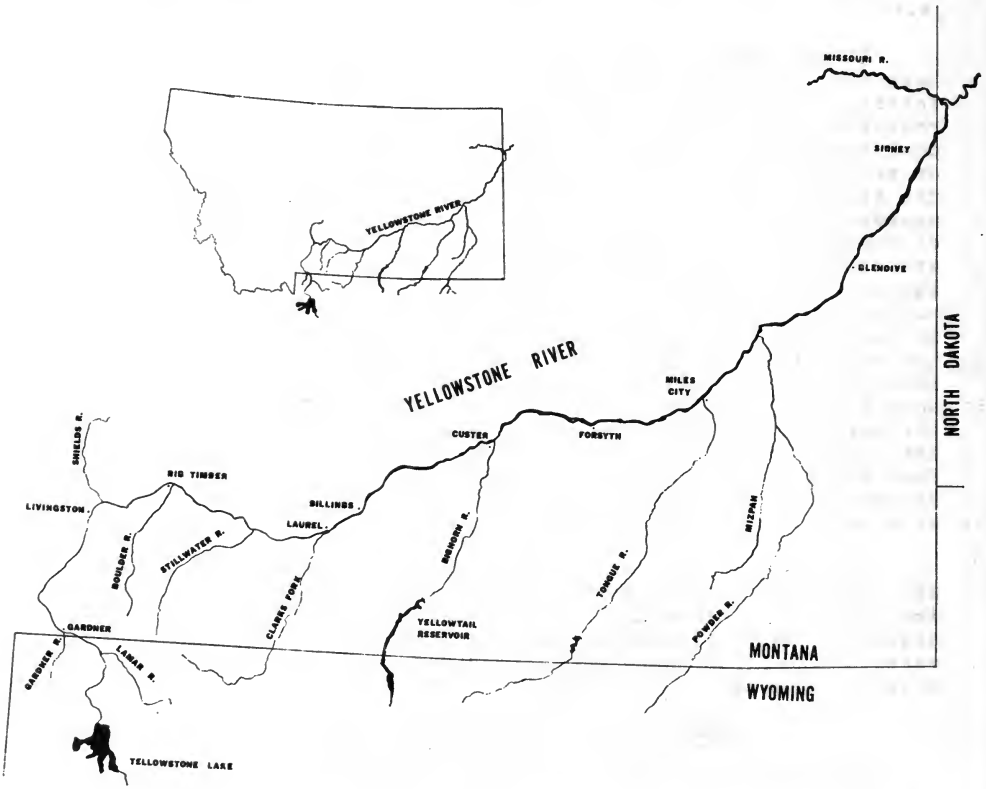

Figure 1. The Yellowstone River and its major tributaries.

The Yellowstone is of great importance as a sport fishery and can be divided into three general zones as related to fish distribution. From its headwaters in Yellowstone Park to its mouth in North Dakota, the river changes from an alpine, salmonid-type fishery to a diverse, warm-water aquatic ecosystem.

The upper Yellowstone, from Gardiner to Big Timber (111 miles), supports cold-water salmonid populations of national significance and has been classified as a Blue Ribbon Trout Stream by the Montana Fish and Game Commission. This area is characterized by large populations of a relatively small number of fish species characteristic of clear, cold-water rivers. The primary trout species are cutthroat, rainbow, and brown trout. Large populations of mountain whitefish exist and longnose sucker are also abundant. The principal forage fish species is the mottled sculpin.

Stream gradients were calculated for the upper river from the mouth of Pine Creek to Big Timber. The average drop in elevation per river mile for this reach is 12.9 feet; however, individual gradients for short sections (two to six miles long) within this area varied from 10.0 to 18.2 feet per mile.

The middle Yellowstone, from Big Timber to the mouth of the Bighorn River (160) miles, contains the transition zone between the primarily cold-water environment of the upper river and the warm-water environment of the lower river. In this area, both cold and warm-water fishes are present, but their distribution and relative abundance are poorly understood at present.

The average river gradient for the middle Yellowstone is 8.1 feet per mile. Gradients for individual sections within this area varied from 5.1 to 11.4 feet per mile.

The lower Yellowstone extends from the mouth of Bighorn River to its confluence with the Missouri River and is approximately 295 miles long. The area supports a diverse aquatic ecosystem containing a wide variety of species commonly known as warm-water fishes. Important sport species found in the lower Yellowstone include paddlefish, shovelnose sturgeon, sauger, walleye, channel catfish, northern pike, and burbot. In addition, large populations of non-sport species occur which represent a lightly utilized but potentially valuable resource.

The average river gradient for the lower river is 2.8 feet per mile. Gradients for individual sections within this area varied from 1.0 foot per mile near Sidney to 5.7 feet per mile near Miles City. The gradient profile of the Yellowstone in Montana is illustrated in Figure 2.

A total of 49 species representing 13 families of fish has been recorded for the Yellowstone River in Montana (Table 1). Fishery investigations in areas of the river not previously sampled will likely add a few new species to the list. The probable distribution of 33 of the 49 species is illustrated in Figure 3.

There is an increase in species diversity progressing

Table 1 . Fish Species Recorded for the Yellowstone River (Family Scientific and Common Names).

ACIPENSERIDAE (Sturgeon family)	
Scaphirhynchus albus	Pallid sturgeon*
Scaphirhynchus platorynchus	Shovelnose sturgeon*
POLYODONTIDAE (Paddlefish family)	
Polyodon spathula	Paddlefish*
HIODONTIDAE (Mooneye family)	
Hiodon alosoides	Goldeye*
SALMONIDAE (Trout family)	
Prosopium williamsoni	Mountain whitefish*
Salmo clarki	Cutthroat trout*
Salmo gairdneri	Rainbow trout*
Salmo trutta	Brown trout*
Salvelinus fontinalis	Brook trout*
ESOCIDAE (Pike family)	
Esox lucius	Northern pike*
CYPRINIDAE (Minnow family)	
Cyprinus carpio	Carp*
Carassius auratus	Goldfish*
Notemigonus crysoleucas	Golden shiner*
Semotilus margarita	Pearl dace
Semotilus atromaculatus	Creek chub
Hybopsis gracilis	Flathead chub*
Hybopsis gelida	Sturgeon chub
Couesius plumbeus	Lake chub
Notropis atherinoides	Emerald shiner*
Notropis stramineus	Sand shiner
Hybognathus hankinsoni	Brassy minnow
Hybognathus placitus	Plains minnow
Hybognathus nuchalis	Silvery minnow*
Pimephales promelas	Fathead minnow*
Rhinichthys cataractae	Longnose dace*
CATOSTOMIDAE (Sucker family)	
Carpoides carpio	River carpsucker*
Cycleptus elongatus	Blue sucker*
Ictiobus bubalus	Smallmouth buffalo*
Ictiobus cyprinellus	Bigmouth buffalo*
Moxostoma macrolepidotum	Shorthead redhorse*
Catostomus catostomus	Longnose sucker*
Catostomus commersoni	White sucker*
Catostomus platyrhynchus	Mountain sucker*
ICTALURIDAE (Catfish family)	
Ictalurus melas	Black bullhead*
Ictalurus punctatus	Channel catfish*
Noturus flavus	Stonecat*
GADIDAE (Codfish family)	
Lota lota	Burbot*
CENTRARCHIDAE (Sunfish family)	
Lepomis cyanellus	Green sunfish*
Lepomis gibbosus	Pumokinseed
Lepomis macrochirus	Bluegill
Micropterus dolomieui	Smallmouth bass*
Micropterus salmoides	Largemouth bass*
Pomoxis annularis	White crappie*
Pomoxis nigromaculatus	Black crappie*
PERCIDAE (Perch family)	
Perca flavescens	Yellow perch*
Stizostedion canadense	Sauger*
Stizostedion vitreum	Walleye*
SCIAENIDAE (Drum family)	
Aplodinotus grunniens	Freshwater drum*
COTTIDAE (Sculpin family)	
Cottus bairdi	Mottled sculpin*

*Species taken in recent sampling

downstream on the Yellowstone. In Yellowstone National Park above Tower Junction, cutthroat trout exist as the only trout species. Eleven species (5 families) of fish have been recorded for the upper Yellowstone River in Montana; however, only six species (4 families) can be considered common or abundant. The middle river contains approximately 20 fish species representing 8 families; however, sampling in this area has been very limited. The lower Yellowstone is the most diverse portion with 45 species representing 12 families having been recorded.

METHODOLOGY

To accomplish the previously stated objective, work is being directed towards equipment development and sampling technique adaptation, field life history studies of important fish species of the lower Yellowstone, and predicting effects of potential flow changes on important life history stages. Important fish species to be studied include the channel catfish, sauger and walleye, burbot, shovelnose sturgeon and pallid sturgeon. Data will also be collected on other species during general sampling surveys. Forage fish species will be identified and investigated and a food habits study will identify forage fish and aquatic insect species important to the major sport fish populations.

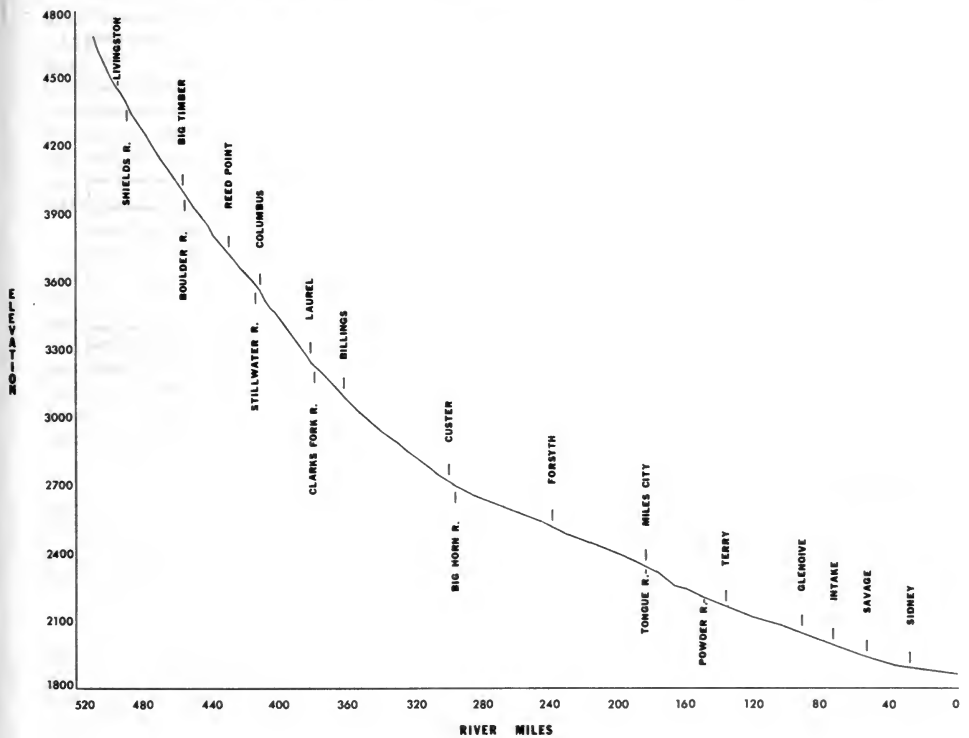

Figure 2. Longitudinal profile of the Yellowstone River from the mouth of Pine Creek to its confluence with the Missouri River.

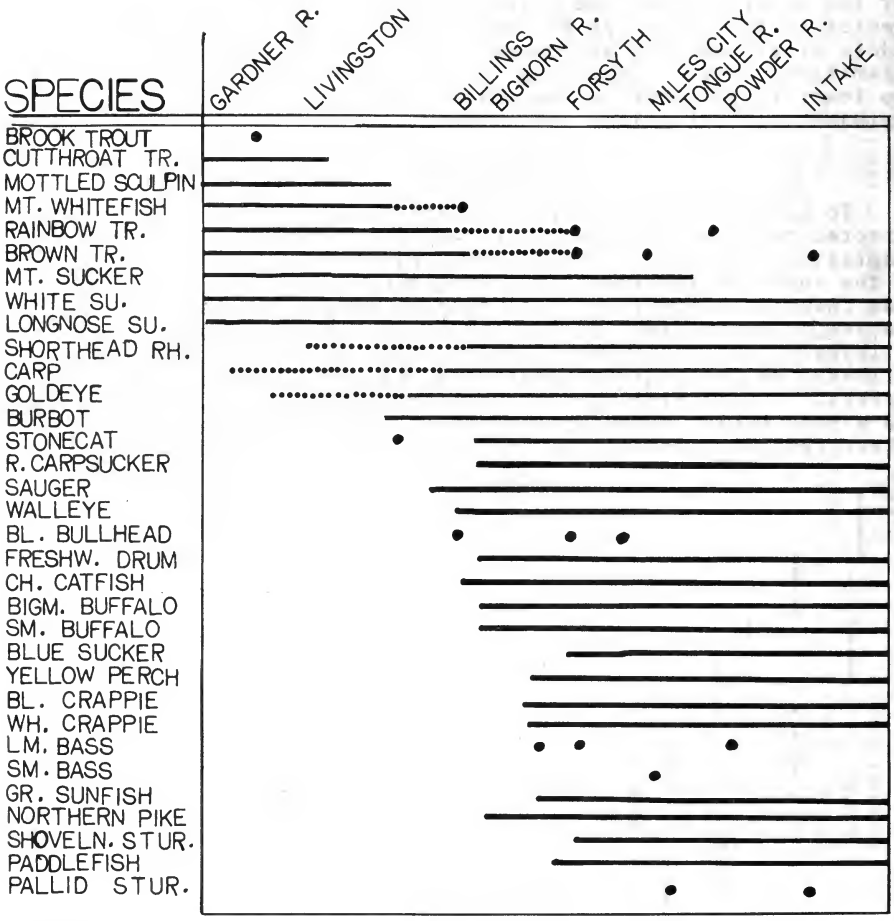

FIGURE 3

LONGITUDINAL DISTRIBUTIONS OF SOME FISHES OF THE YELLOWSTONE RIVER IN MONTANA

BROKEN LINES DENOTE RARE OR OCCASIONAL OCCURENCE; WIDE LINE INDICATES REPRODUCTIVE SUCCESS IN THE AREA; DOTS INDICATE OCCURRENCE OF A SINGLE OR A FEW INDIVIDUALS.

The large size of the lower Yellowstone combined with relatively high current velocities, seasonally turbid conditions, and a large, diverse fish fauna present unique and extremely difficult sampling problems. Therefore, equipment development and sampling technique adaptation must necessarily precede any intensive life history investigations. For complete life history investigatons, it is desirable to sample all sizes of fish including eggs, fry, Age 0, subadults, and adults during all seasons of the year. Following is a discussion of the methods developed for two sport species of fish under intensive investigation (shovelnose sturgeon and sauger) and for sampling backwater habitat types of the river.

Adult shovelnose sturgeon were readily captured in the lower Tongue and Yellowstone Rivers by drifting large mesh gill nets (2 1/2 to 4-inch square measure) in areas relatively free from snags during spring, summer, and early fall. Shovelnose were extremely difficult to capture during late fall using this technique. Young shovelnose (less than 0.5 pounds) were captured by dead setting 125 foot experimental gill nets (1/2 to 2 1/2-inch mesh square measure) off of the downstream end of gravel bars and islands with the small mesh end set downstream. We have been unsuccessful in capturing fry and fingerling shovelnose.

The primary method for capturing adult sauger in main channel and backwater areas of the lower river consists of electrofishing with AC or DC current utilizing a variety of electrode arrangements suspended from fiberglass poles off the front of the boat. Since electrofishing success is dependent upon water temperature, conductivity, and light penetration conditions, the efficiency of this method is both daily and seasonally variable. Age 0 sauger were captured by seining shoal and backwater areas in late summer with a 100-foot 1/4-inch mesh seine, and electrofishing selected habitat types with a mobile electrode unit and DC current.

Backwaters are areas that characteristically have slack or very slow moving water and are generally formed from side channels when water levels decline after high water. Occasionally backwaters occur at the mouths of some tributary streams when the tributaries cease flowing in mid-summer. Since the formation and maintenance of backwater areas are dependent on the stage heights of the river, a severe or long-term reduction in water levels will eliminate or greatly reduce many of the present backwater areas.

A study was designed and implemented to determine the importance of backwater areas to the river fish populations. Principal areas of investigation include species utilization, seasonal utilization, reproduction and rearing, and forage fish production of backwater areas.

To accomplish this, backwaters will be sampled on a monthly basis by first isolating the backwater with block nets and then intensively electrofishing, seining, and gill netting the area. During periods of increased fish activity, the sampling periodicity will be increased. Water quality and temperatures will be monitored in backwaters under study and in adjacent main channel areas. Since this study is just getting started, presentation of initial data is not warranted at this time.

The prediction of impacts arising from potential water development projects on the Yellowstone requires a determination of the instream flow needs of the species of fish inhabiting the river. This in turn, requires relatively complete knowledge of the life history of the species involved. It is unrealistic to assume that complete life histories of all species inhabiting the lower river will or can be determined: however, certain critical aspects, (reproduction and rearing, habitat requirements, food habits, and movements) of the life history of important sport species will be thoroughly studied. Once the physical needs of these species have been identified, the Bureau of Reclamation's Water Surface Profile Program will be used to relate these species needs to the computed physical channel and flow characteristics found at reduced flow levels.

PRELIMINARY RESULTS

Shovelnose Sturgeon

The shovelnose sturgeon descended from a primitive group of bony fishes (subclass Palaeopteryii) which was dominant during the Palaeozoic era. The living descendents of this group found in the lower Yellowstone include the paddlefish, pallid sturgeon, and shovelnose sturgeon.

The shovelnose sturgeon is common in the Ohio, Mississippi, Missouri, and Yellowstone Rivers. The Yellowstone, however, is the only major river where shovelnose are found which has not been significantly altered by dam construction and/or channelization and offers a rare opportunity to study this species in a largely unregulated river system. The closely related pallid sturgeon is found throughout the larger streams and reservoirs of the Mississippi - Missouri River system but occurs only rarely (1).

The shovelnose is a popular sport species in the lower Yellowstone and investigations into the distribution and life history requirements of this species were initiated in April of 1974. Since only one year's data are available, no firm conclusions can be drawn; however, preliminary results are presented here.

The shovelnose is reported to spawn from May to July (1); however, its actual spawning habits are largely unknown. During the spring of 1974, a sizable spawning run from the Yellowstone into the lower 20 miles of the Tongue River was documented and monitored. During the period from April 4 to July 8, 1974, 427 shovelnose were captured in the lower Tongue. Four hundred twenty of these were tagged and released for future movement and spawning studies to determine migration patterns, spawning periodicity, and degree of homing. Although the first sturgeon was captured on April 4, sizable numbers of fish did not enter the Tongue until May 9. The period from May 13 through May 23 was characterized by low catch rates and corresponded to a drop in water temperatures caused by climatic conditions (Figure 4). During the last week in May, water temperatures and catch rate again increased. The last sampling occurred on July 8; however, sturgeon were probably present in the Tongue for a longer period.

Exact spawning times and locations were not determined during this sampling; however, ripe male shovelnose were captured from May 29 through the end of the sampling period and one ripe, partially spent female was captured on June 4. Future research will be aimed at determining exact spawning times, locations, and water conditions and capture of larval shovelnose.

The average length of 427 shovelnose captured during this period in the Tongue was 30.2 inches (fork length) and ranged from 20.9 to 40.1 inches (fork length). The average weight of these fish was 5.35 pounds and ranged from 2.10 to 15.5 pounds. (Verification of identification of larger specimens by Dr. W. Gould, Assistant Leader, Cooperative Fisheries Unit, Montana State University). Twenty-six percent of the total number of fish captured weighed 6 pounds or more, 11 percent weighed 8 pounds or more and 5 percent were 10 pounds or heavier (Figure 5). These fish are significantly larger than shovelnose reported elsewhere in the country. Out of 4,000 sturgeon examined from the lower Missouri River, the average size was approximately one pound while fish over 4 pounds were rare (14). From a sample of 6,000 shovelnose taken from the Mississippi River bordering Iowa, the average size was between 2 and 3 pounds (5) while the largest fish observed was 33.6 inches long (fork length) and weighed 6.2 pounds (4). The size difference between Mississippi and Missouri River shovelnose is not directly comparable since the Tongue River sample came from a suspected spawning run and a larger average size would be expected from mature adult fish than from samples taken randomly from the entire population. Nevertheless, the large number of fish captured in the Tongue over the maximum size reported for the two other areas is highly significant.

Limited shovelnose sturgeon sampling was done during May, 1974, in the Yellowstone below the Rosebud diversion at Forsyth and below the Intake diversion structure at Intake. The average fork length of 32 sturgeon captured at Forsyth was 32.1 inches and varied from 27.6 to 36.1 inches. The average weight was

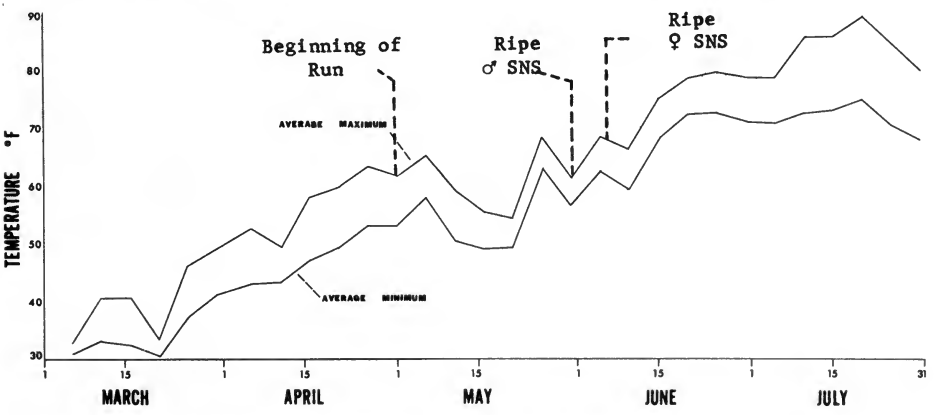

Figure 4. Average 5-day maximum-minimum temperatures of the lower Tongue during spring and summer of 1974.

6.20 pounds and ranged from 3.86 to 9.65 pounds. By contrast, a sample of 16 shovelnose collected below Intake during the same time period averaged 25.2 inches in length and 2.19 pounds in weight. Weights for individual fish ranged from 1.14 to 3.10 pounds. Interpretations at this early stage in the study and from that small a sample size are not warranted at this time.

Future research on the shovelnose will include investigation of migration patterns, spawning requirements, habitat requirements, and food habits in an attempt to determine the instream flow needs of this species.

Sauger and Walleye

The sauger is one of the more important sportfish in the lower Yellowstone River. The most popular and productive areas for sauger angling are below the lowhead irrigation diversion structures in the lower river, such as the Rosebud Diversion at Forsyth and the Intake Diversion below Glendive. Other popular sites are at the mouths of tributaries such as the Bighorn and Tongue Rivers. A significant sauger fishery also occurs seasonally in the lower Tongue River.

The sauger is native to Montana and is found in both the Yellowstone and Missouri River drainages. It is common in the Missouri below Great Falls and the Yellowstone below Billings (1). The closely related walleye is not native to Montana but has been widely introduced. It is much less common than the sauger in the lower Yellowstone, but probably has a distribution similar to that of the sauger.

There is a lack of relevant literature pertaining to sauger and walleye in lotic environments. Morris (9) felt the lack of such data may be due to the difficulties in sampling large flowing waters, and the relatively low population densities which may occur in such environments. Sauger investigations were initiated in 1973 to gather data on certain life history aspects of this species in the Yellowstone as well as information on distribution and abundance.

During the fall (September through November) of 1973, five areas of the lower Yellowstone were sampled using 125 foot experimental gill nets. The five areas of the river sampled were in the vicinities of Myers, Forsyth, Miles City, Terry and Intake, and sauger were taken at all these locations. Catch rates for gill nets set in the five areas ranged from a low of 1.13 fish per overnight net set at Myers to a high of 3.83 at Terry (Table 2). During this fall gill netting, a variety of habitat types were netted including quiet waters and those in association with various current velocities. The lack of quiet water areas in the Terry area required all nets to be fished in areas with moderate current, thus possibly selecting preferred sauger habitat. A total of 171 sauger were taken in 89 overnight net sets for a combined catch rate of 1.92 sauger per net set. Average size of these Yellowstone River sauger (Table 2) are similar to those reported by Posewitz (12) for the Missouri River and tributaries.

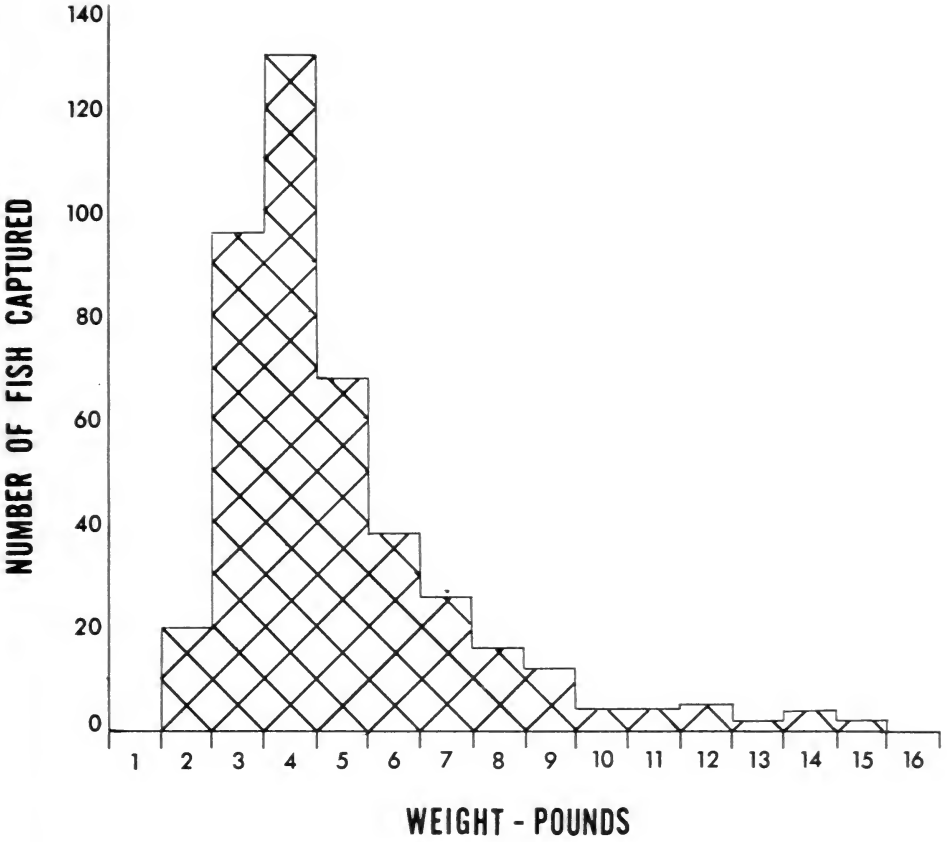

Figure 5. Weight-frequency of 427 shovelnose sturgeon captured in the lower Tongue River from April 4 to July 8, 1974.

Table 2. Catch rate and average lengths and weights and range for sauger taken in gill nets from five areas of the lower Yellowstone River during the fall (September - November) 1973.

	Myers (15)	Forsyth (24)	Miles City (33)	Terry (6)	Intake (11)
Number of sauger per net set	1.13	2.04	1.45	3.83	3.09
Average Weight (lbs)	1.0	1.3	0.7	0.7	0.8
Range	0.7-1.4	0.4-3.8	0.2-2.4	0.2-2.5	0.1-3.2
Average Length (inches)	14.9	15.4	13.0	12.8	13.3
Range	13.2-17.2	10.3-21.4	8.1-19.7	9.0-19.4	7.9-21.0

During April and May, 1974, a one mile section of Yellowstone River below the Rosebud diversion at Forsyth was monitored in an attempt to obtain estimates of the number of sauger in this section, to define spawning periods and locate spawning areas, and to tag a number of fish to study possible movements.

A total of 495 fish, including 295 sauger and 13 walleye were marked and released in this section. Nineteen sauger were recaptured, providing a 6.4 percent return of marked sauger. The Schnabel estimator was used to estimate sauger numbers in the run during the sampling period. Since the sauger estimate was made on what is thought to be a spawning run and new fish were continually entering the area, several conditions which Chapman and Overton (2) believe necessary to make a valid estimate using the Schnabel estimator were not met. Ricker (13), however, felt the estimator could still be useful, even though some conditions were not met.

It was estimated that 2,024 sauger were present in this one mile section during the sampling period. Confidence intervals (2) at the 80 percent level were 1,564 to 2,867. While this estimate cannot be considered accurate, it is probably indicative of the magnitude of the sauger numbers present. Mean length and weight for 301 were 15.4 inches and 1.2 pounds, respectively, ranging from 6.6 inches and 0.1 pounds to 26.8 inches and 6.5 pounds. The largest sauger may have been a sauger x walleye hybrid. Sauger taken in this section in spring averaged larger than those taken in fall gill net samples and may be indicative of a spawning run composed primarily of larger, mature fish. Spawning runs of sauger and walleye in rivers have been documented by a number of other workers (3, 6, 7, 9, 11, and 15).

Sauger and walleye were apparently spawning in the study section during the sampling period. The first ripe male sauger and ripe female walleye were taken during the last week of April.

Ripe female sauger were not taken until the second week of May. A spent female sauger was taken on May 20 along with several spent female walleyes. Water temperatures ranged from 42°F to 61°F during the sampling period (Figure 5). Based on recaptured spent females (walleyes and sauger), spawning was known to have occurred between May 16 and 20, when water temperatures were 45°F to 52°F.

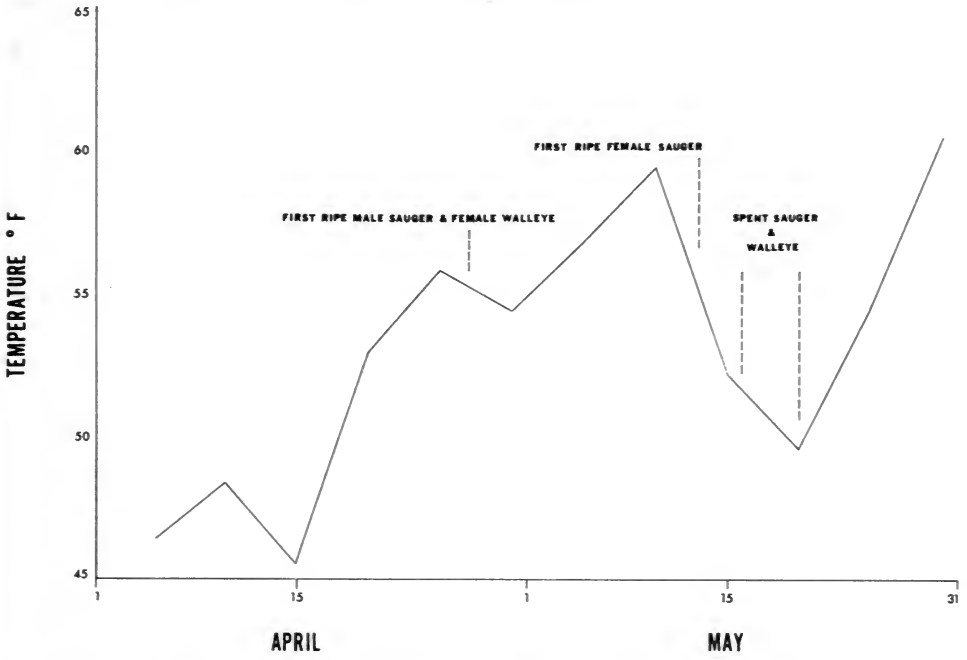

Figure 6. Water temperature and documented sauger and walleye spawning period in the Yellowstone River at Forsyth during spring, 1974.

Mature sauger and walleye were commonly taken in water 1 to 4 feet deep with a sand or gravel bottom and a moderate current. Areas meeting these requirements are numerous in the lower Yellowstone and further investigations may locate abundant suitable spawning areas.

Movements

A total of 15 tags from sauger tagged in the study section at Forsyth were returned by anglers. Eleven tagged sauger showed no movements and were caught in the study section, while four fish exhibited extensive upstream movements which averaged 53.3 miles. One sauger tagged several miles upstream from the Forsyth study area on April 17, 1974, was caught at the mouth of the Tongue River on April 22, 1974, exhibiting a total downstream movement of 55 miles in five days.

CONCLUDING REMARKS

The problem of predicting effects, and proposing alternatives to minimize impacts, of proposed water developments on the lower Yellowstone is indeed complex. The need for quality information for an accurate assessment of impacts is obvious. Gathering this information is costly and time consuming, yet it is a necessary part of the planning process. Most of us here are involved with or responsible for managing a resource. That resource may be anything from coal and oil to land and water to fish and wildlife. The well-being and enjoyment of future generations very likely may depend on how well those resources are managed now.

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ASSESSMENT AND IMPLEMENTATION OF "IN-STREAM VALUE STUDIES" FOR THE NORTHERN GREAT PLAINS

By Ken Bovee*

INTRODUCTION

When water is removed from a river system, the hydrologic regime of the river is changed below the point of diversion. Subtle changes may occur in the flow characteristics, in the insect fauna, in the fish community, and in the character of the floodplain as a result of such dewatering. The changes become more pronounced as more water is removed from the system.

Physical changes in a dewatered stream include a reduction in both the depth and velocity of the water (4, 7, 8), and a reduction in the transport of sediment by the river, although the supply of sediment is likely to remain constant. This condition may lead to deposition, or aggradation of the streambed (6). Summer water temperatures will likely be higher than normal, and during the winter, portions of the river may freeze solidly from top to bottom.

Reduced streamflow also has a pronounced effect on water quality. Organic wastes are not diluted as much, and in conjunction with higher summer water temperatures, decomposition may result in depletion of the dissolved oxygen in the stream. Because of reduced velocities and increased temperatures, evaporation of remaining river water will increase, contributing to a concentration of dissolved salts. The salinity may become high enough to render the water unusable for irrigation or other uses.

To counteract these problems, a certain portion of the streamflow may be designated as "in-stream, or reserved" flow. This designation refers to a recommended discharge which must be left within the confines of the channel. While a flow reservation cannot over-ride the prior water rights of farmers and ranchers, it may compete with contemporary water applications from industries. Therefore, the flow recommendation must be reliable for the protection of the river, defensible in the face of competing demands, and expedient for the agencies or personnel making the recommendation.

The University of Montana, in co-operation with the Montana Department of Fish and Game, is presently field testing one method of recommending minimum streamflow requirements. This methodology combines variations of the methods used by the Washington Department of Ecology and the Oregon Fish Commission for making flow reservations for anadramous fisheries.

METHODOLOGY

The basic premise of this synthesized methodology is that

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areas of shallow, fast water will be more severely affected by dewatering than will areas of deep slow water (3). If these areas are maintained, then the river itself will be protected.

Flow criteria for these shallow areas are established through the use of indicator species. For spawning criteria, migrant fish species such as the paddlefish (*Polyodon spathula*) and the sauger (*Stizostedion canadense*) are suggested as the indicators. If these species can migrate, they can probably also spawn. Because they typically spawn in fast, relatively shallow water, these species will be most severely impacted by reduced streamflow during the spawning season. As yet, no flow criteria have been established for these species.

During the rest of the year, or the rearing period, the suggested indicator species is the stonecat (*Noturus flavus*). This species was selected for its preference of fast, shallow water areas. Flow criteria have been tentatively established for this species from data collected during the autumn of 1974. Riffle utilization by stonecats was examined by electrofishing techniques as described by Vincent (12). The locations of captured stonecats were marked with small buoys, and the parameters of depth, velocity, and bottom type were measured and recorded for each buoy.

It was determined that stonecats in the Tongue River are normally associated with substrates ranging in size from small cobbles (6.4 cm median diameter) to boulders, with a heavy utilization of rocks in the 128 to 256 mm size class. The mean depth of 203 samples was 45 cm, with a standard deviation of 13.7 cm. The average velocity of the samples was 64.4 cm/sec, with a standard deviation of 19.6 cm/sec. Table 1 illustrates the occurance of stonecats as a function of depth and velocity.

Table 1: Occurance of stonecats as a function of depth and velocity

VELOCITY (cm/sec) \ DEPTH (cm)	< 15	16-30	31-45	46-60	61-75	> 76
< 15	0	0	1	1	1	1
16-30	0	0	3	0	0	0
31-45	0	6	7	10	8	1
46-60	0	3	23	27	7	1
61-75	1	8	18	21	2	1
76-90	0	3	24	11	1	0
91-105	0	0	4	4	0	0
> 106	0	1	3	1	0	0

The outlined block in Table 1 contains 61% of all samples. The depths and velocities and represented by that outline are suggested as flow criteria for the rearing period. This includes depths of 30 to 60 cm, and velocities of 45 to 90 cm/sec. over a substrate of medium cobble to boulder. 78% of all stonecats were found within this range of depths, and 74% within this range of velocities.

These data can be used to evaluate different discharges over areas of stonecat habitat by means of hydrologic mapping. Four transects are established at intervals of 5 to 7 meters across the study area, and the depth, velocity, and distance from shore, measured at 1.5 meter intervals across each transect. This data is then recorded to scale on separate gridded maps for depth and velocity. Contour lines of equal depth and equal velocity are drawn, using interpolation to locate points between transects. Figure 1 is an example of a depth contour map, and figure 2 shows a velocity contour map.

A composite map is constructed on gridded tracing paper to outline areas meeting the criteria for both depth and velocity (Fig. 3). The actual area of preferred habitat may then be determined planimetrically. This area is then plotted against discharge for several different discharges. From this plot, the recommended minimum discharge may be determined (Fig. 4). If the plot is in the form of Figure 4a, the recommended minimum discharge is given as 75% of the optimum discharge (2). However, if the data plot is in the form of Figure 4b, the recommended minimum should be at the top inflection point.

Passage discharges may be evaluated by the "usable width method" as developed by the Oregon Fish Commission (11). Under this approach, the shallow bars most critical to passage of adult fish are located, and a transect established which follows the shallowest course from bank to bank. At each of several discharges, the total width and the longest continuous portion of the transect meeting passage criteria are measured. These data are then plotted vs. discharge, and the discharge meeting the flow criteria on 50% of the total transect width, and a continuous portion of 30% (subject to revision pending establishment of criteria) may be suggested as the minimum passage and spawning flow. This method applies to streams in which the paddlefish is the spawning indicator species.

For reaches of streams which do not contain spawning paddlefish, the sauger is suggested as the indicator species. Flow criteria may be estimated from the literature, but should be field measured, if possible. Pending further study, suggested criteria for sauger spawning are depths of 1 to 1.5 meters and velocities of 30 to 75 cm/sec over clean gravel bars (3). This criteria is evaluated using the mapping method described earlier.

OVER-RIDING CONSIDERATIONS

In the Northern Great Plains, there are three physical parameters which may require a greater discharge than the fishery, per se. These are: (1) the formation of surface ice during the winter, (2) the transport of sediment during the spring and early summer, and (3) the water temperature and associated water

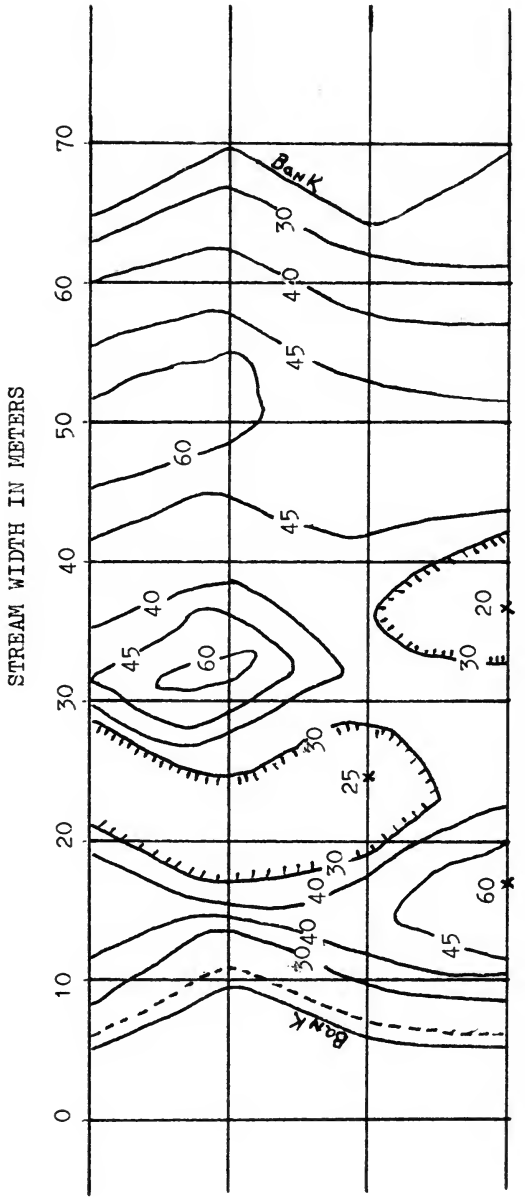


Figure 1: Contour Map for Depths in Hypothetical Mapping Section.

Depths in cm.

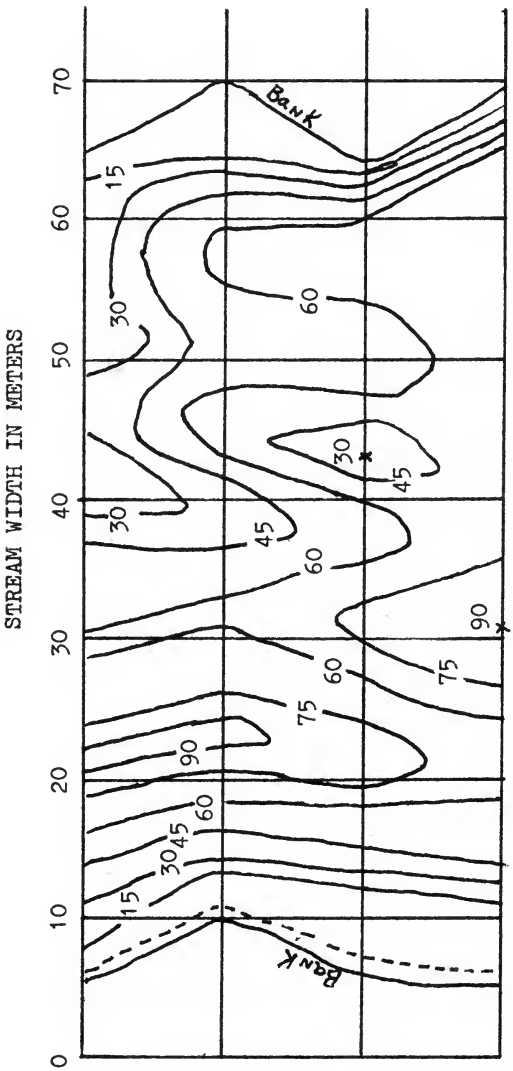


Figure 2: Velocity Contour Map of Hypothetical Mapping Section

Velocity Contours in cm/sec.

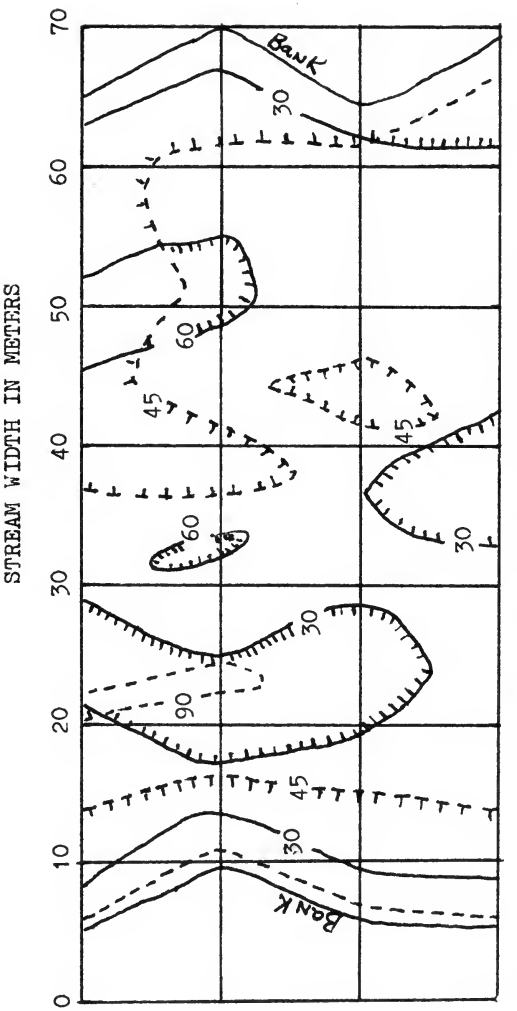


Figure 3: Composite Map of Hypothetical Mapping Section.
Depth Criteria Outlined by Solid Lines,
Velocity Criteria Outlined by Dashed Lines.

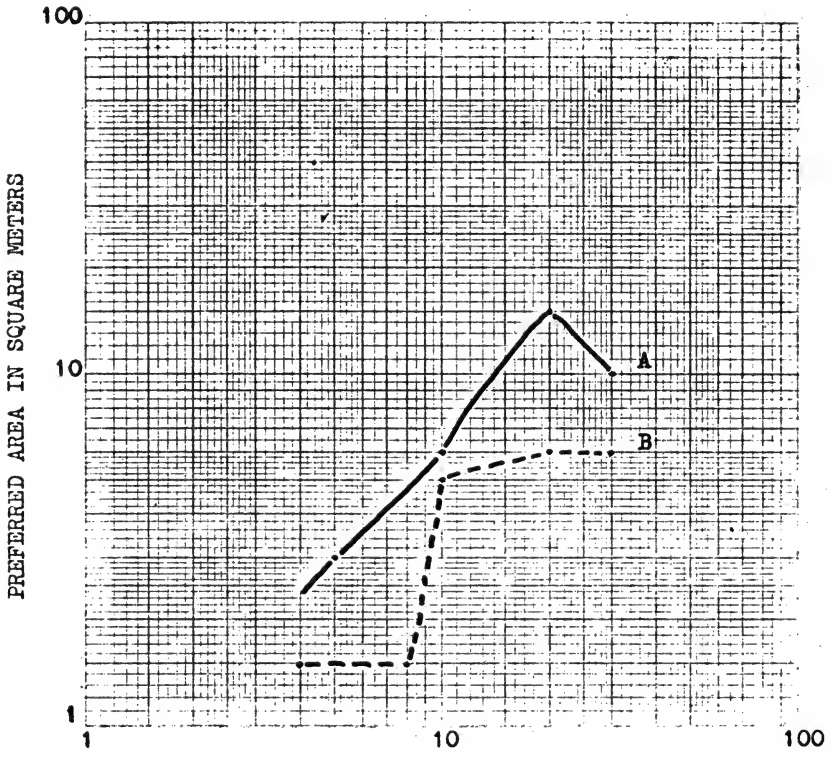


Figure 4: Sample plot of mapped area meeting preferred criteria, as a function of discharge. Curve A: typical of elongated bars with deep thalweg. Curve B: typical of "flat" riffles with uniform flow conditions and poorly defined thalweg.

quality parameters during the late summer. At this time, preliminary results are available on the formation of ice from the literature and from measurements made this winter.

It is remarkable that so little basic information is available concerning a phenomenon as commonplace and important as surface ice formation. In general, the first formation of ice occurs after the entire water mass is near the freezing point. When the surface film is cooled even slightly below the freezing point, frazil ice forms on the surface by nucleation. The degree of supercooling required is seldom more than..01 °C, although the ambient air temperature must be considerably colder than 0 °C (10).

If the turbulence is large, discs of frazil ice are carried below the surface, and the body of water is converted to a slushy mixture of ice and water. If the turbulence is not sufficient to cause mixing, the ice crystals form small floating islands of loosely connected ice. Within the interstics between the ice crystals, liquid water is trapped and rapidly frozen.

As ice crystals form, the heat of fusion is released, creating convection currents over the river. The banks, being exposed to colder air than are areas in the center of the river may then become much colder. As these floating islands of ice strike the supercooled banks, they adhere and freeze rapidly to them (9). Eventually, the entire river surface is closed in from both sides, creating a continuous ice cover.

Once this ice cover has formed, the ice sheet thickens primarily by conduction and frazil ice capture. Since ice is a poor conductor of heat, the temperature gradient is steep, and the rate of freezing rapidly decreases as the sheet thickens (9).

The thickness of ice formed by conduction in a given time increment may be determined from the equation

$$E = \sqrt{\frac{2\Theta Kt}{LS}} \qquad (1)$$

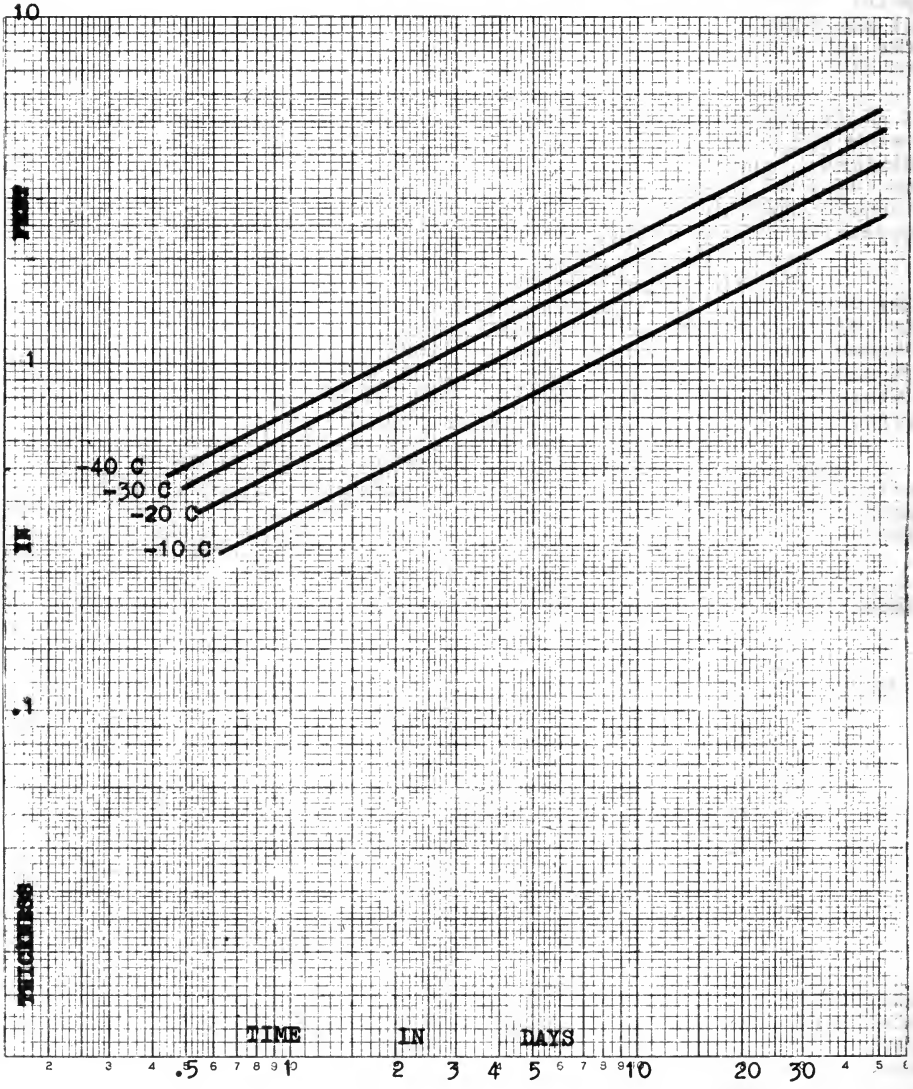
Where,

E = ice thickness in cm
Θ = ambient air temperature in degrees C
K = thermal conductivily of ice = .0057 cal/deg/cm^2/ sec
t - time in seconds
L = heat of fusion = 80 cal/gram
S = density of ice = .9166 gram/ cm^3

Figure 5 shows the rate of growth of the ice sheet by conduction at four different temperatures. If the growth of the ice sheet were due solely to conduction, such growth should be very slow and not influenced by currents. In addition, the sheet should be of near uniform thickness. In reality this is not usually the case.

The strength of the current essentially determines the

Figure 5: Rate of Growth of Ice Sheet by Conduction at Four Different Temperatures. From Barnes (1).



contour of the under surface of the ice. When submerged frazil ice encounters an area of reduced velocity and turbulence, it rises to the surface and rapidly freezes to the underside of the existing ice sheet. Therefore, in areas of rapid current, there is less opportunity for the frazil ice to adhere to the surface layer (1). This phenomenon is illustrated in Figure 6, where ice thicknesses and water velocities were measured across a transect of known bed conformation. Notice that the under surface of the ice is roughly parallel to the streambed, except where water velocities are high. At present, the rate of frazil ice capture and its relation to current velocity is not quantifiable. This is a relatively untouched area of research and presents an excellent opportunity for further study.

In terms of stream dewatering, it should be apparent that a reduced winter streamflow could have serious consequences. As the stream's velocity is reduced, the capture of frazil ice may proceed more rapidly, thereby increasing the ice thickness. Concurrently, the depth of water will also be reduced, so that over shallow areas, the envelope of open water between the ice and the streambed may be restricted or eliminated altogether. These areas are extremely important to the production of invertebrate fauna, so the extension of surface ice to the bottom over extended areas of riffle is likely to reduce productivity, and thereby affect the fishery.

DISCUSSION AND CONCLUSION

The methods outlined above for recommending minimum streamflows have several advantages and disadvantages. They afford a graphical representation of actual, quantified stream flow paramters, which adds greatly to the reliability and credibility of the results. However, the methods are very definitely time-consuming, not only in data collection, but in data preparation and in waiting for the proper discharge to occur. Perhaps the most serious deficiency of the methods, is that only those discharges occurring normally can be measured. There is no way to predict the flow conditions at discharges below the minimum measured discharge. If the critical discharge lies within this unmeasured portion, the results may be more subjective and less reliable than methods based on historic flow records.

To overcome this deficiency, the Bureau of Reclamation, through its Technical Assistance Program, has offered a unique solution which offers expediency, and which has the promise of reliability. The Bureau has designed a computer simulation model which utilizes inputs of surveyed cross-sections, water surface elevations, distance between cross-sections, and descriptions of roughness parameters, along with a measurement of discharge. Output from the model includes water surface elevations, velocities in up to nine portions of each cross section, tractive force, conveyance areas and widths, hydraulic radii, and discharges (5). The model is currently being field tested on several Montana streams, and will be applied to the Tongue River sections this spring. Results from the model will be checked against field measurements from the detailed data methods described earlier.

The Bureau has made a significant contribution to the flow

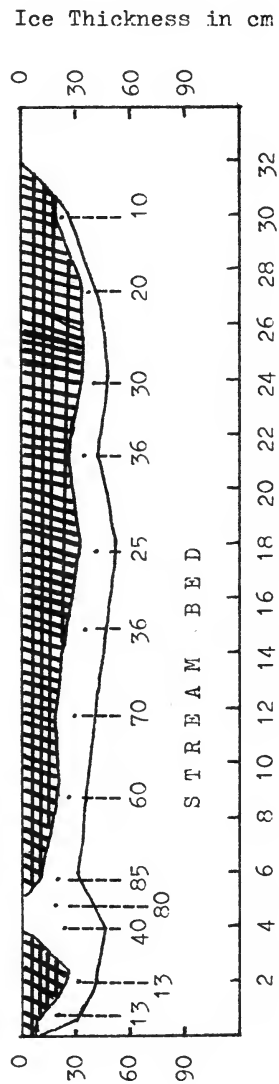


Figure 6: Ice thickness and current velocity across a fairly uniform transect. Velocities in cm/sec.

recommendation methodologies, and should be congratulated for its efforts. If the method is as reliable as is hoped, the constraints of the detailed data methods will be largely eliminated. This will allow researchers more time for the equally important investigation of flow criteria and some of the overriding considerations outlined in this paper.

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FISH DISTRIBUTION AND DIVERSITY OF A MONTANA PRAIRIE STREAM

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ABSTRACT

Fish populations of the Tongue River were sampled to determine species composition, distribution, and diversity for various habitat zones of this prairie stream. Electrofishing gear, baited hoop nets and traps, a beach seine and large meshed gillnets were utilized to sample the fish populations in six primary and five secondary sampling sections. Twenty-nine species of fish were collected from the Tongue River during 1974 of which three (burbot, shovelnose sturgeon and blue sucker) were considered migrant. Six species ranged the length of the stream. Irrigation diversion structures influenced longitudinal distribution of fish in the Tongue River. Sucker distribution grades from predominately longnose immediately downstream from the Tongue River Dam to white suckers in mid-reaches, with shorthead redhorse dominance downstream. Smallmouth bass, sauger and channel catfish were the dominant sport fish. Species diversity indicies were calculated, showing a general increase with downstream progression, indicating an increase of rarer species in the lower reaches. A total of 1,060 fish were tagged in the river with a total angler return rate of 1.51 percent, suggesting an under utilized fishery resource.

BACKGROUND

The headwaters of the Tongue River rise in the Bighorn Mountains of Wyoming. The river generally flows northeast out of Wyoming, to its confluence with the Yellowstone River at Miles City. Flows in Montana are controlled by the Tongue River Dam. This 3,500-acre impoundment was constructed in 1938 by the Montana Water Resources Board as an irrigation storage reservoir. Above the reservoir, the river meanders through a broad open valley with a wide floodplain. Turbid water, slow velocity, muddy bottoms and warm temperatures characterize the stream. Downstream from the dam, the river flows for 10 miles through a narrow, restrictive canyon. As gradient increases, water temperatures cool and gravel bottoms are common. From the canyon to the river's mouth, the valley again broadens and physical characteristics change from those of the canyon into a slow, meandering prairie stream.

The Tongue River is important to the people of southeastern Montana. It provides water for domestic use by man and livestock, irrigates crops and offers recreation. As coal development threatens the Tongue River drainage, the river takes on a new importance. The Decker-Birney Resource Study of April, 1974, identified strippable coal reserves underlying 359,333 acres of the planning unit in the Tongue River drainage. Approximately

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285,000 acres of this planning unit is composed of superior reserves - containing 15 billion tons of coal - which are economically feasible to mine. Other coal reserves exist outside the Decker-Birney unit, yet are associated with the Tongue River.

The Tongue River and Tongue River Reservoir will become increasingly important in light of proposed coal development. While most coal mined in Montana now leaves the state, coal conversion complexes (steam-fired generation, gasification and liquefaction plants) close to the coal source loom on the horizon. Such energy complexes require great amounts of water and the Tongue is considered an important source of industrial water.

In 1972, a new Tongue River dam site was identified by the Montana-Wyoming Aqueduct Study. The new reservoir would inundate about 12 more miles of Tongue River and provide an additional 60,000 acre-feet of water. The magnitude of the proposed industrial use of the Tongue River makes it imperative that fish populations are inventoried and that adequate flow levels are insured to protect the fishery.

Fish population studies in Montana have received far less attention in warm water streams than in cold water streams. Two important aspects of warm water stream investigations are lacking; (1) few estimates of total fish population numbers have been made, and (2) fish collecting methods have not been devised and evaluated for warm-water environments (9). Early interest in the high esteem placed on trout fishing has been the primary cause of differences. Another factor is the greater difficulties encountered in working warm-water streams with their more diversified habitats and larger, more varied fish populations.

The objectives of this study were to inventory the warm-water fish populations of a prairie stream to determine species composition, distribution and diversity for various habitat zones.

METHODS

Major habitat zones were delineated for the Tongue River through the use of aerial photos, U.S.G.S. quad maps, and on ground observations. Physical characteristics were determined with the aid of the Water Surface Profile Program, developed by the Bureau of Reclamation. This program allows the users to predict and/or study changes in stream characteristics at different flows. The program model is calibrated to a specific stream section using one or two observed flows, the corresponding water surface elevations, and cross sectional data at various locations in the stream section (4). These measurements are obtained through standard surveying methods.

Water temperatures were monitored utilizing a Taylor 30-day recording thermograph. The recording sheets were changed monthly. Daily maximum-minimum temperatures were tabulated. All water temperatures were recorded in Farenheit degrees.

Fish populations were sampled by several methods. Electrofishing gear with an output of 0-500 volts variable direct cur rent was utilized to sample fish populations in the river (12).

Baited hoop nets (3-foot hoops with 1-inch mesh webbing) and wire frame traps were fished for channel catfish. A 100-foot, 1/4-inch mesh beach seine and a 4-inch bar mesh gill net were also utilized to sample fish populations. Numbered Floy filament tags were used to mark fish. Fish population statistics were calculated by computer as described by Vincent (13). Species diversity indicies were calculated according to the formula described by Shannon and Weaver (10).

PHYSICAL PARAMETERS

Collection areas were established on 11 reaches of the river downstream from the Tongue River Dam (Figure 1). Primary sampling sections (I B, II B, III A, IV B, V B, V C) were established in relation to irrigation diversion structures to evaluate fish distribution (Table 1). Section V B was established as a major sampling sect on since the New Tongue River Dam was located in the section. Sections ranged in length from 8,200 feet to 13,332 feet, while gradients varied from 2.94 feet/mile near the mouth to 6.67 feet/mile in the canyon. There was a decrease in gradient progressing downstream. Secondary sections (I A, II A, III B IV A, V A) were established to delineate fish distribution in the river.

Water temperatures were recorded at station I A from March - December. Temperatures greater than 70° were recorded for 92 days and 47.8 percent of those days the temperature exceeded 80°. The maximum temperature recorded was 90° in mid-August. The mean monthly maximum and minimum temperatures are shown in Figure 2.

Table 1. Description of major sampling sections, Tongue River.

Section	Location (miles) 1/	Upstream Barrier	Length (ft)	Gradient (ft/mile)
I B	14.1	T and Y Diversion	12,650	2.94
II B	70.5	S-H Diversion	11,669	3.57
III A	90.6	Mobley's Diversion	13,332	4.00
IV B	156.7	Brewster's Diversion	11,669	3.45
V B	177.5	Tongue River Dam	8,870	6.67
V C	186.6	Tongue River Dam	8,200	6.45

1/ River miles above the mouth

FISH POPULATIONS

Species Distribution

Twenty-nine species of fish representing 10 families were collected during 1974 on the Tongue River. Common names of fishes used in this report correspond to those presented by the American Fisheries Society (2). Of these species, three (burbot, shovelnose sturgeon and blue suckers) were taken only during spring sampling near the mouth and are considered to be migrant

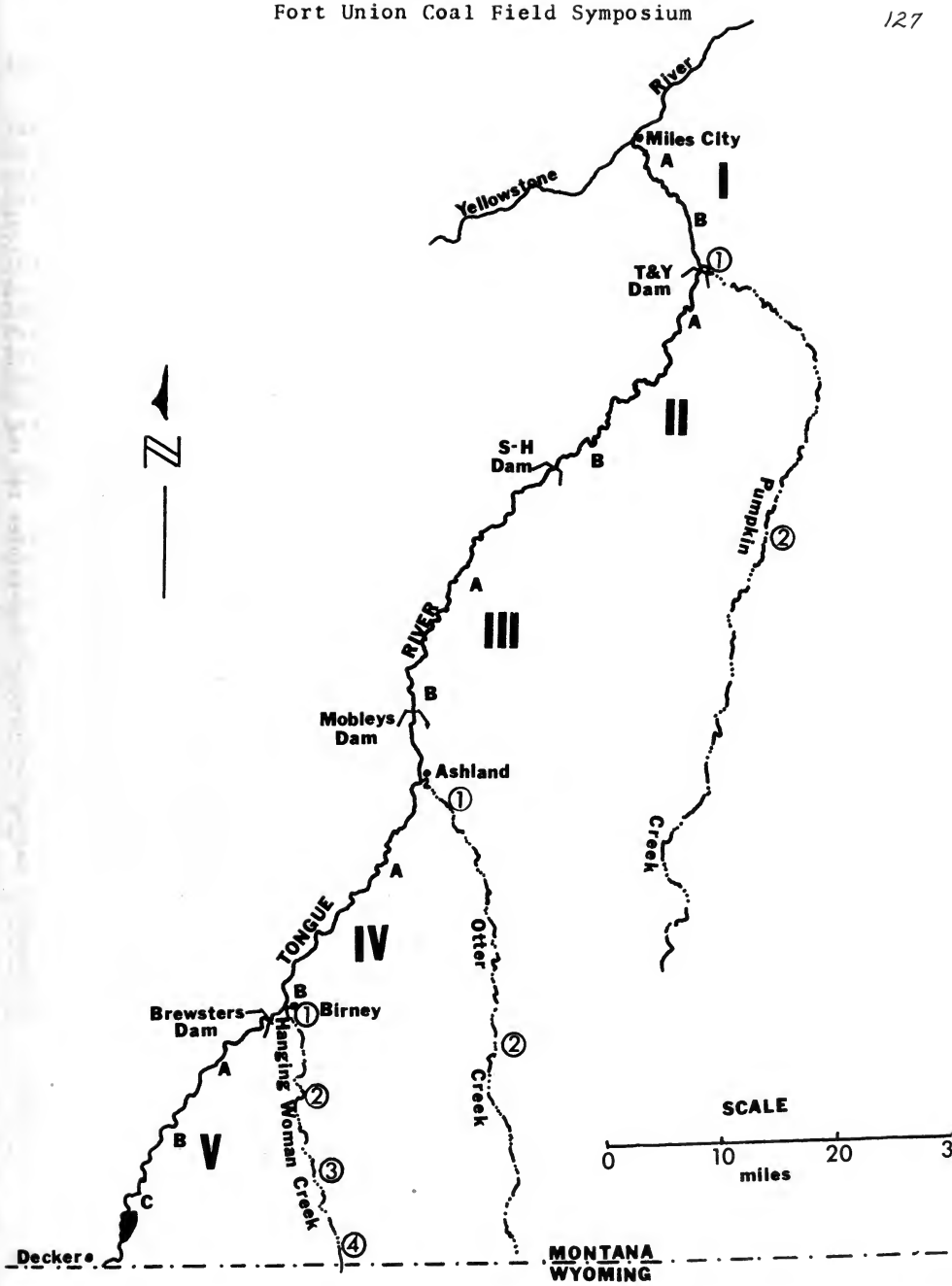

Figure 1. Map of Tongue River showing sampling sections and major tributaries.

Figure 2. Mean monthly maximum and minimum temperatures for the Tongue River, 1974.

species.

The nature of the qualitative distribution is shown in Table 2. Grouping by sections obscures the variation encountered but illustrates broad trends of fish distribution. Six species ranged the length of the stream. Mountain whitefish and brown trout were confined to the upstream zone.

Longitudinal distribution of fish in the Tongue River is influenced by irrigation diversion structures. The T and Y diversion is the upstream limit for goldeye, walleye, burbot, shovelnose sturgeon, blue suckers and sturgeon chubs. Channel catfish did not occur above the S-H diversion. Flathead chubs are found upstream from the Mobley diversion, but in limited numbers when compared to downstream sections. Brewster's diversion is the upper limit for river carpsuckers and smallmouth bass.

Population Numbers and Species Composition

The fall electrofishing samples are summarized in Table 3, expressed as numbers and pounds of fish collected per mile of stream. Each sample is made up of six electrofishing trips. Numerically, flathead chubs were dominant in sections I B (30.1 percent of the total number) and III A (45.7 percent), followed by shorthead redhorse (19.9 and 20.2 percent, respectively). Shorthead redhorse were dominant in sections II B (30.9 percent), and IV B (37.2 percent). Carp dominated sections I B and II B by weight, while shorthead redhorse predominated sections III A, IV B, and V C. White suckers dominated section V B both numerically and by weight and longnose suckers were dominant in Section V C. Sucker distribution grades from predominately longnose in section V C, to white sucker dominance in section V B, with shorthead redhorse dominance in the remaining reaches (Figure 3).

Game fish concentrations were heaviest in section IV B and made up 12.7 percent of the total number, with smallmouth bass the dominant game fish. Smallmouths ranged in length from 2.1 to 13.5 inches and the preponderance of young-of-the-year fish indicates that they are successfully reproducing. Smallmouth bass were also found downstream from the S-H diversion, but the greatest concentration was near Birney.

Northern pike were also captured in Section IV B. The inclusion of small notherns (9.3 inches in length) suggests that these fish are also reproducing in the river. The lower reaches of Hanging Woman Creek would provide excellent northern pike spawning habitat and probably acts as a nursery area for the Tongue River population of northerns.

The Tongue River supports the only rock bass population in Montana. Greatest numbers of rock bass were found in sections IV B and V B. All size classes were represented in the samples.

The greatest number of channel catfish was found in section II B, with the largest fish weighing 7.25 pounds. Sauger were most abundant near the mouth, in section I B, and made up 13.1 percent of the total numbers captured. The largest sauger

Table 2. Distribution of fishes in the Tongue River by zones, in 1974.

	ZONES				
Species	V	IV	III	II	I
Carp	*	*	*	*	*
Stonecat	*	*	*	*	*
Shorthead redhorse	*	*	*	*	*
White sucker	*	*	*	*	*
Longnose sucker	*	*	*	*	*
Longnose dace	*	*	*	*	*
White crappie	*	*		*	*
Mountain sucker	*	*	*	*	
Rainbow trout	*	*	*		
Rock bass	*	*	*		
Black crappie	*	*			
Yellow perch	*	*			
Northern Pike	*	*			
Whitefish	*				
Brown trout	*				
Green sunfish		*	*	*	
Smallmouth bass		*		*	*
Pumpkinseed		*			*
Black bullhead		*	*		
Flathead chub		*	*	*	*
Sauger		*	*	*	*
River carpsucker		*	*	*	*
Channel catfish				*	*
Goldeye					*
Burbot					*
Walleye					*
Shovelnose sturgeon					*
Blue sucker					*
Sturgeon chub					*
Total No. Species	15	20	14	14	19

Table 3. Summary of electrofishing samples for the Tongue River, fall, 1974; expressed as number of fish per mile of stream (total weight shown in parenthesis).

	I B	II B	II A	IV B	V B	
Goldeye	33(17.5)					
Mt. Whitefish					1(0.2)	
Rainbow trout				1(0.9)	2(4.0)	18(20.3
Brown trout						3(2.6)
Northern pike				3(18.8)		
Carp	58(102.1)	65(118.3)	4(8.4)	27(86.4)	33(16.5)	79(214.9)
Flathead chub	133(6.6)	148(13.3)	165(11.6)	5(0.3)		
Sturgeon chub	1(T)					
Silvery minnow			2(T)			
Fathead minnow		1(T)				
Longnose dace	3(T)	2(T)	15(0.3)	1(T)	3(0.1)	
River carpsucker	26(26.0)	130(49.4)	4(2.7)	45(39.2)		
Shorthead redhorse	88(69.5)	216*(116.6)	73(47.5)	283*(274.5)	14(15.3)	296(731.1)
Longnose sucker	8(4.8)	47(27.3)	21(16.0)	62(65.1)	76(14.4)	770(1239.7)
White sucker	8(6.0)	8(12.1)	22(12.8)	125(87.5)	311*(307.9)	151(249.2)
Mountain sucker		1(T)	7(0.4)		1(0.3)	8(1.1)
Black bullhead			1(0.1)	1(0.6)		
Channel catfish	7(18.3)	24(70.3)				
Stonecat	9(0.6)	40(2.0)	41(3.3)	65(7.2)	82(0.8)	34(4.1)
Rock bass		1(0.3)	5(1.6)	30(4.2)	11(1.8)	
Green sunfish		1(T)	1(T)	7(0.3)		
Pumpkinseed	1(0.1)			7(0.1)		
Smallmouth bass	1(0.2)	2(0.5)		88(9.7)		
White crappie	2(0.3)	2(0.3)	2(0.3)	2(0.5)	2(0.2)	1(T)
Black crappie	1(0.1)			1(0.1)	1(0.1)	
Yellow perch				3(0.2)	4(0.4)	10(0.6)
Sauger	58(56.3)	11(9.9)	11(9.9)	5(4.6)		
Walleye	5(5.3)					
Total	442(313.7)	699(420.3)	361(106.0)	761(600.2)	541(362.0)	1370(2463.6)
No. of Species	17	16	14	19	13	11

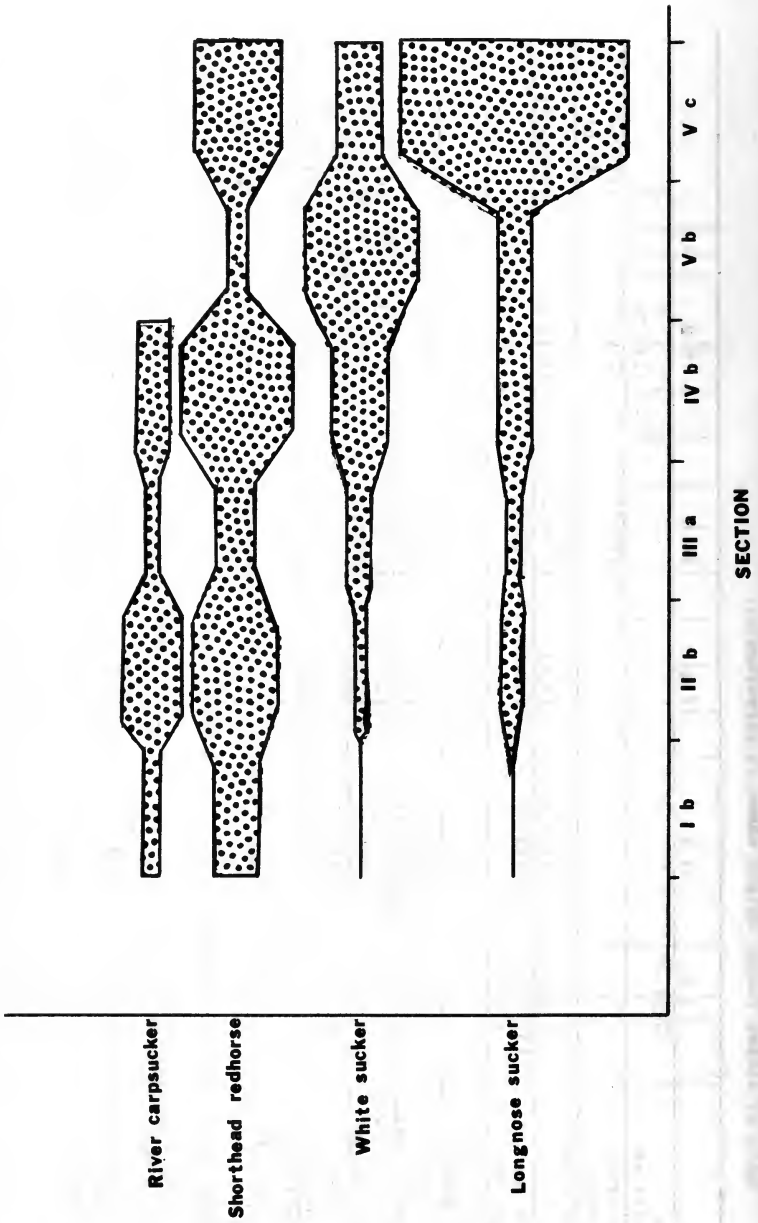

Figure 3. Longitudinal distribution of suckers in Tongue River. The width of the line indicates abundance.

caught weighed 4.90 pounds.

Species Diversity

Species diversity indicies have been used by biologists to provide insight into the structure of natural communities and as possible indicators of qualitative aspects of their surrounding environments. A low diversity index (d) indicates a largely monotypic community dominated by a few abundant organisms, while a high diversity index suggest a heterogeneous community in which abundance is distribued more evenly among a number of species (Robert Newell, personal communication). Redundancy (R) was also used as an index of the repetition of information within a community, expressing the dominance of one or more species and is inversely proportional to the wealth of the species (14).

While species diversity indicies have been used extensively with benthic macroinvertebrates to evaluate degradational environmental conditions, they have recently been applied to fish populations (11, 7, 5). Indicies of species diversity (d) and redundancies (R) were calculated for the 6 primary sampling sections on the Tongue River. The diversity indicies increased with progression downstream (Figure 4), indicating an increase of rarer species in the lower reaches. One exception was section IV B, which did not fit the curve. This section had the greatest number of species, many represented by few individuals. However, as Jackson and Harp (7) showed, longitudinal distribution in a stream is not necessarily a continuous change since specific conditions and populations may reappear at intervals throughout the stream system. Redundancy substantiates the d concept since R increases with dominance by one or more species (Figure 4). Fish populations in the upstream sections were dominated by one or two species represented by a large number of individuals. And the populations in the lower reaches lack a strongly dominant species.

Measures of species diversity add another handle to the quantitative and qualitative description of a fishery. By collecting baseline data, a change in the fish population can be observed by comparing diversity and redundancy. It is a generally accepted concept that a large-scale environmental stress exerted upon a diverse biological community results in a reduction of species diversity (3).

Tagging

A total of 1,060 fish were tagged in the Tongue River during 1974 to evaluate movements and relative angler harvest (Table 4). Migrant shovelnose sturgeon, sauger, walleye, channel catfish and other non-sport fish were tagged in the spring in an attempt to determine home ranges of these fish in the Yellowstone River. Of 421 shovelnose sturgeon tagged, only 3 (0.71 percent) fish were returned, all from the Yellowstone. Sauger tag returns were also higher in the Yellowstone than in the Tongue (2.33 percent as compared to 0.33 percent respectively). A total angler return rate of 1.51 percent suggests a fishery resource that is not being utilized by anglers.

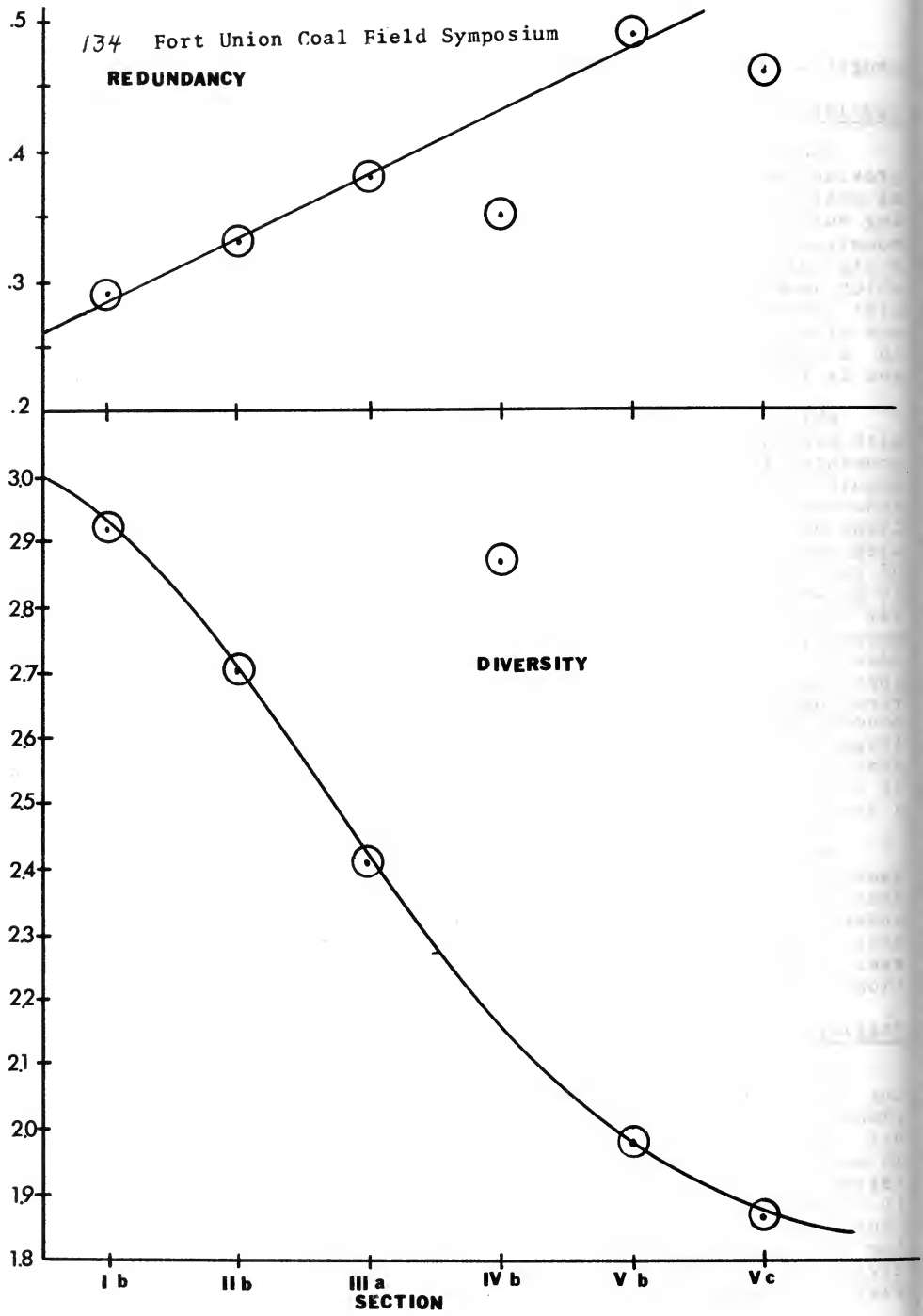

Figure 4. Species redundancy and species diversity curves for numbers of individuals for the Tongue River.

Migrant Fish Populations

Sampling during the spring of 1974 in the lower reaches of the Tongue revealed a large number of fish moving into the river from the Yellowstone. Sauger concentrations became obvious from fishermen use during mid-April and continued to use the Tongue until spring run-off precluded sampling efforts. Maximum water temperatures during this period ranged from 55° to 70°. Shovelnose sturgeon first became apparent around the 5th of May

Table 4 Summary of fish tagging and angler returns, Tongue River, 1974. (Percent returns shown in parenthesis).

Species	Number Tagged	Tongue River	Yellowstone River	Total
Shovelnose sturgeon	421	-	3 (0.71)	3 (0.71)
Sauger	301	1 (0.33)	7 (2.33)	8 (2.66)
Channel catfish	194	1 (0.52)	1 (0.52)	2 (1.03)
Smallmouth bass	34	1 (2.94)	-	1 (2.94)
Rock bass	33	-	-	-
Rainbow trout	28	1 (3.57)	-	1 (3.57)
Walleye	16	1 (6.25)	-	1 (6.75)
Burbot	11	-	-	-
Blue sucker	11	-	-	-
Northern pike	5	-	-	-
White crappie	3	-	-	-
Bigmouth buffalo	2	-	-	-
Drum	1	-	-	-
Total	1060	5 (0.47)	11 (1.04)	16 (1.51)

when water temperatures reached 66°. Sturgeon were also present during high water, and were still in the river through July 8. Gravid males were caught before runoff, but no ripe females were captured. Blue suckers were captured coincidental with sauger sampling and were in breeding condition, with tubercles. This collection documented the second known record of these unusual suckers in the Yellowstone drainage.

DISCUSSION

Streams vary greatly in size, velocity, gradient, nature of the bed, temperature and other features. Generally, streams change from the steep torrent to the sluggish meandering waterways as they proceed from source to mouth (1). Usually there are stages between the two extremes which are characterized by specific environmental features and a particular assemblage of fish species.

Many attempts have been made to associate particular fish faunas with these defined zones. Huet (6) devised a scheme for European streams using four categories, naming each zone from the characteristic fish species found in them. In descending order of current velocities they are:

(1) The trout zone:
(2) The grayling zone:
(3) The barbel zone:
(4) The bream zone:

Each of these zones is characterized by a particular set of combinations of stream gradient and stream width. North American streams have been classified by zones by Lagler, et. al. (8) as follows:

(1) Grayling
(2) Stream char
(3) Flowing water minnows and pike
(4) Basses
(5) Catfishes, suckers and quiet water minnows

As the gradient diminishes, the headwater fishes disappear and are replaced successively by others better adapted to the changing environment.

Fish populations in the Tongue River exhibit a succession from torrent zones fishes (trout) to the quiet zone fishes (catfish and suckers). Fish population data suggest that the Tongue River mimics the fish distribution, fish species diversity, and fish species zonation of the Yellowstone River, which is also extremely important to the scope of energy development. The results of the Tongue River Study will be compared to fish population studies currently being conducted in the Yellowstone main stem. This will aid in determining similarities with (or defining differences between) the Tongue sub-basin and the entire Yellowstone River Basin.

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* * *

APPLICATION OF U.S. BUREAU OF RECLAMATION WATER SURFACE PROFILE PROGRAM (WSP)

John M. Dooley*

INTRODUCTION

The Bureau of Reclamation has used various methods to compute water surface profiles for many years. These methods, for the most part, have concentrated on determining reservoir backwater elevations and tailwater elevations below various instream structures.

The Montana Fish and Game Department has the task of determining stream maintenance flows for rivers and streams and sections of rivers and streams throughout Montana. After the stream maintenance flow has been determined, a water right to insure this flow's availability must be established. Physical parameters needed to determine the proper stream maintenance flow include; flow velocities, flow quantities, water depths, water surface elevations, and cross sectional areas. These data can be collected through actual field measurements of many flows or can be determined with one set of field measurements and computations with a Water Surface Profile Program.

In late 1973 and early 1974, after many contacts between the Montana Fish and Game Department and the Bureau of Reclamation's Upper Missouri Regional Office, a cooperative venture of technical assistance was started. This Technical Assistance Program allows the Bureau of Reclamation to share its technical expertise and computer capability with a State agency.

DESCRIPTION OF WSP

WSP is a computer adaptation of the Bureau of Reclamation's Water Surface Profile Computation Method B. The Water Surface Profile Program was written to computerize computations necessary to determine tailwater and backwater elevations. These are the water surface elevations below dams and control structures and above reservoirs. The hand calculations needed to compute these elevations are very tedious.

WSP is adaptable to instream applications. The program allows the user, after sufficient field work, to predict and/or study various changes in stream characteristics at many different flows. The predicted values are within the accuracy of the field data. The program (model) is calibrated to a specific stream section using one or two observed flows, the corresponding water surface elevations, and cross sectional data at various locations in this stream section. Stream characteristics determine the number of cross sections needed to sufficiently describe a stream study section. These characteristics include steepness of the stream or stream gradient, size of the stream, stream meanders (bend), bottom roughness, debris in the stream channel, and bridge crossings or diversion structures. In

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essence the number of cross sections needed will vary from stream to stream.

FIELD DATA REQUIREMENTS

Field data needed for input to the WSP Program include the information previously mentioned plus a physical description of the stream section. Quality of this field data determines the accuracy of the computed results. These field data include:

1. Map showing stream section being studied and cross section locations,

2. Cross section survey data.

3. Distance between cross sections,

4. Measured flow in cubic feet per second,

5. Corresponding water surface elevations at all cross sections,

6. Photographs of the stream reach and cross sections,

7. Description of the stream bottom at each cross section, (sand, gravel, cobbles, boulders, muck),

8. Description of bank and overbank material and vegetation (trees, brush, grass, logs),

9. Identification of points where streambed material, vegetation, and streambank change within the cross sections.

If elevations of the water surface elevations and cross section elevations are accurate to within $\pm$ .1 of a foot, the predicted water surface elevations will be accurate within $\pm$ .1 foot. Accuracy of results depends directly upon accuracy of field data.

Figures 1 and 2 show a typical stream section to be studied, without the cross section locations and with the cross locations established. Cross sections should be taken at right angles to the streamflow. Distance between cross sections should be measured along the line of flow or along thalweg (deep part of channel). Measurements should also be made at inside and outside of stream meanders. Critical sections or control sections should be included as a cross section. Where specific information in a transect is desired, for example, a spawning area, feeding area, or a resting area, be sure to include cross sections of that area. Figures 3 and 4 show some typical plotted cross sections.

When a bridge is located in the study reach, cross sections must be taken 50-100 feet above and below the bridge and at the bridge opening itself.

The most downstream cross section should be at a stream control. This means a point in the river or stream where flow control is affected on the stream by a constriction, riffle, or bottom change.

TYPICAL STREAM Study Section

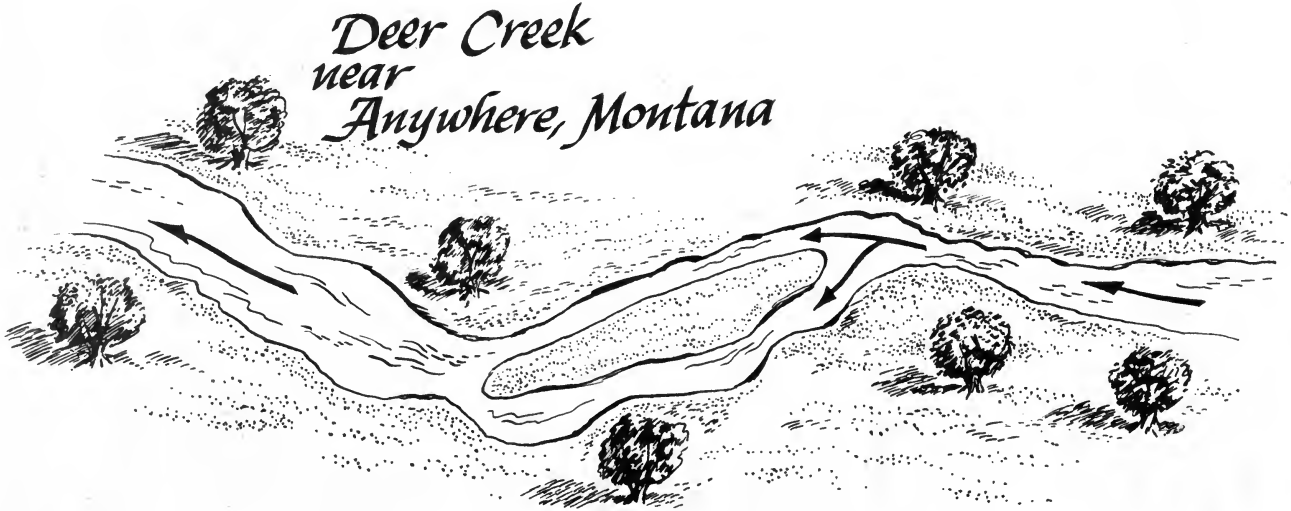


FIG. 1

TYPICAL STREAM Study Section WITH CROSS SECTION LOCATIONS

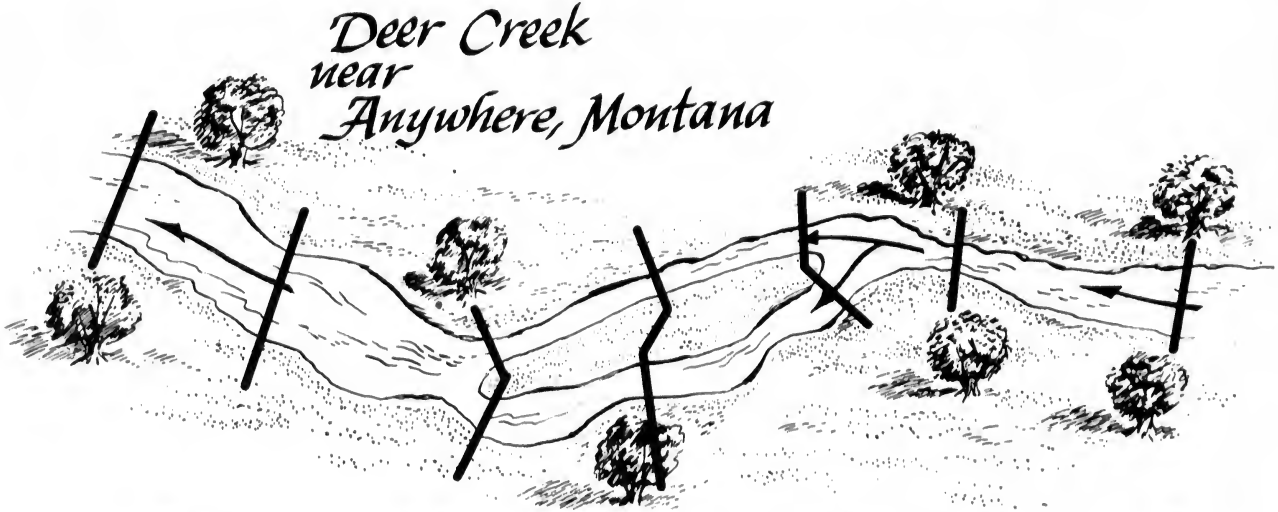


FIG. 2

Consistency is the most important point when taking field data. Cross sections should originate from the same side of the stream if possible. The left streambank is identified as left when looking downstream. Cross sections should be taken in order whether progressing upstream or downstream.

DATA PROCESSING

After the field data is taken, cross sections plots are made (See Figure 3). The data is then readied for keypunching and processing with the computer. An edit program is used to check the keypunched field data for errors. Roughness coefficients ("n" values) are then determined from the field data, observations, and photographs. The data are then processed using the Water Surface Profile Program (WSP). WSP processes the data in a step-by-step manner from the most downstream section through the most upstream section. An energy slope is determined from the streambed thalweg and observed water surface elevations. These observed water surface elevations have been associated with the measured streamflow as mentioned previously.

CALIBRATION

The computer output for the observed flow is examined to determine if predicted water surface elevations match observed values. Adjustments in roughness coefficients ("n" values), cross sections, and station distances are made to bring predicted values within + .1 feet of the observed values. After these adjustments have been made, a series of flows that include a probable low flow or observed low flow and the probable maximum flood flow are setup. These flows are ranged to give a good rating curve for the most downstream cross section. This set of flows including the observed flow is combined with the cross sectional data and processed using WSP to compute the final output.

OUTPUT

Available output from WSP includes specific data for each cross section and summary tables of data for all flows run. Specific cross section output includes water surface elevations, flow velocities in the cross sections, tractive force (amount of force exerted upon stream bottom), conveyance areas and widths, hydraulic radius, and discharges (see output section). Summary table information includes water surface elevations, velocities, discharges, roughness coefficients, tractive forces, and main channel distances for the set of flows that have been used.

From the output data a water surface profile showing water surface elevations, streambed thalweg, and cross section location (by station) is plotted (Figure No. 5). A rating curve for the most downstream section is also plotted (Figure No. 6).

The cross sectional data, computer output, water surface profiles, and rating curve are all returned to the investigator.

Use of these data will aid in determining stream maintenance flows and the effects higher or lower flows have on fish habitat. The output will enable the user to predict changes

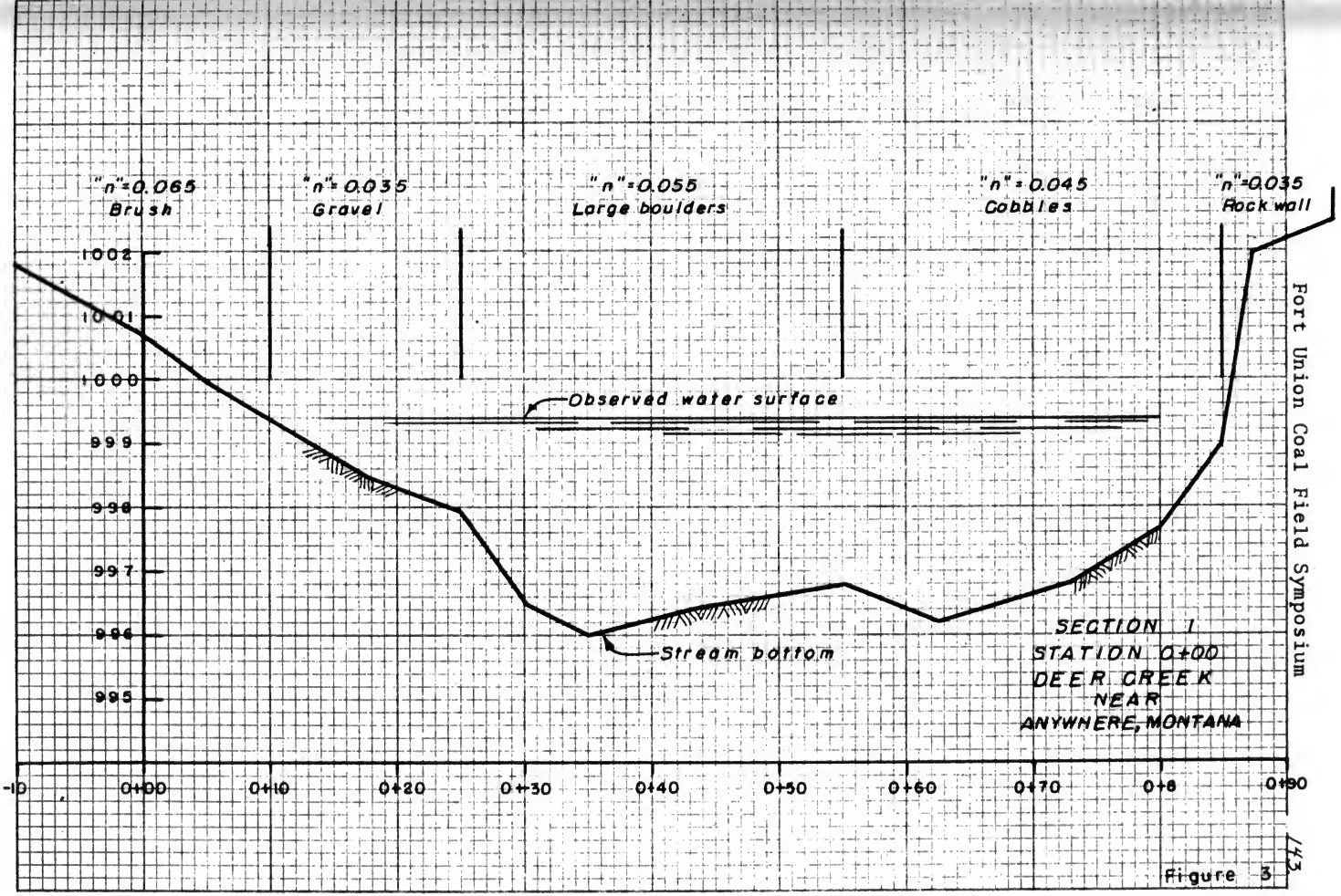

"n"=0.065
Brush
"n"=0.035
Gravel
"n"=0.055
Large boulders
"n"=0.045
Cobbles
"n"=0.035
Rock wall
1002
1001
1000
999
998
997
996
995
Observed water surface
Stream bottom
SECTION 1
STATION 0+00
DEER CREEK
NEAR
ANYWHERE, MONTANA
-10
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+8
0+90

Figure 3

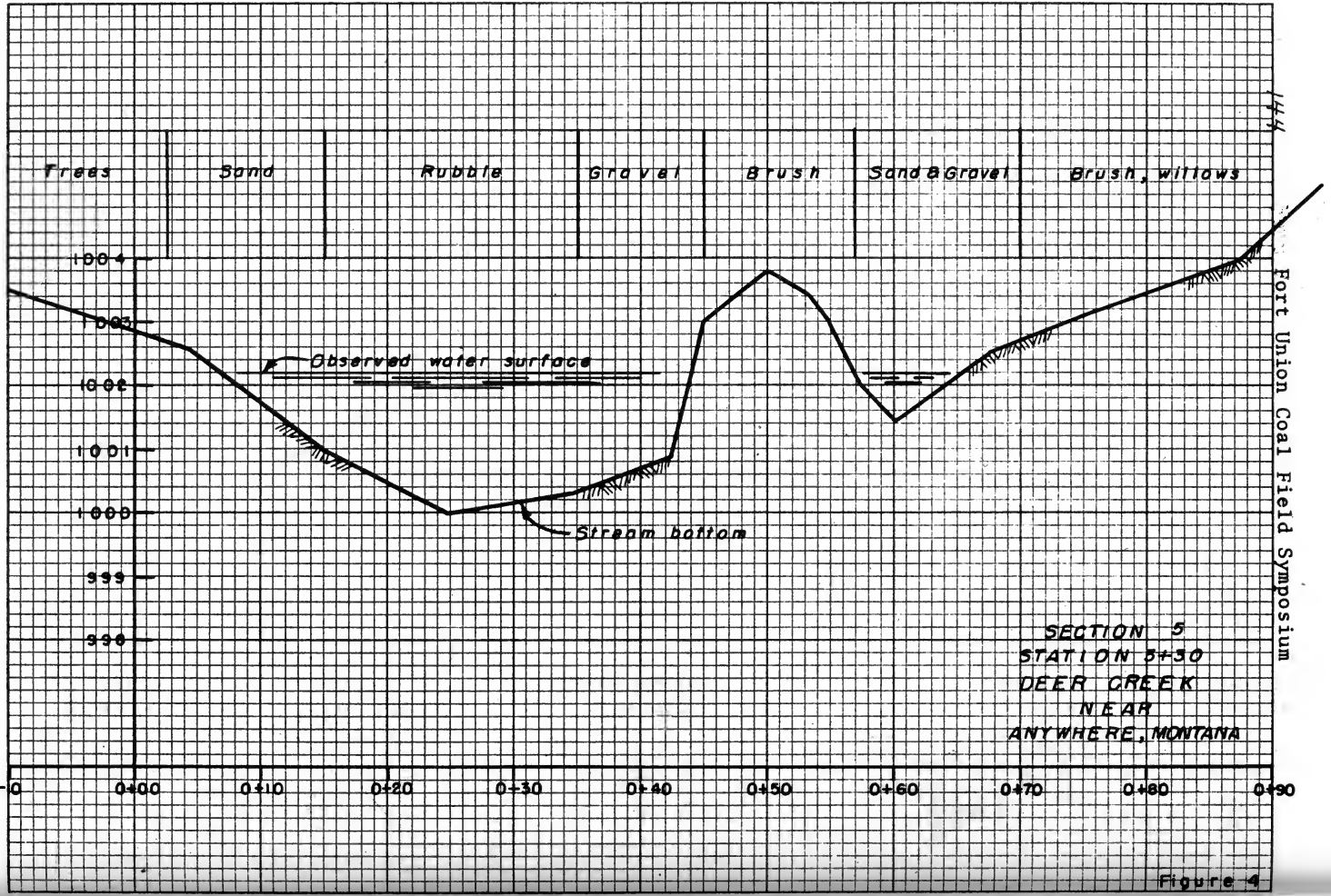
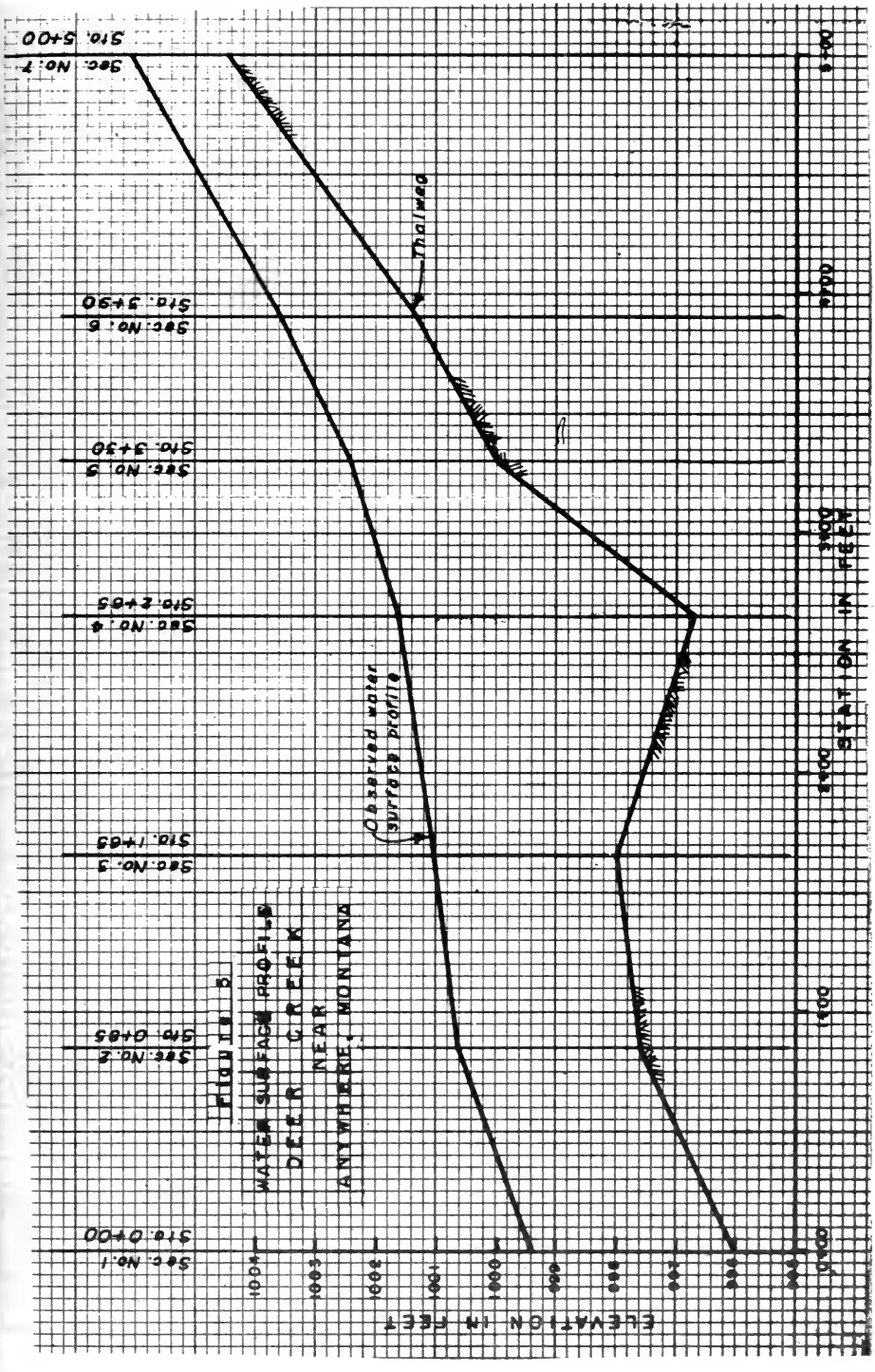

Trees
Sand
Rubble
Gravel
Brush
Sand & Gravel
Brush, willows
1004
1003
1002
1001
1000
999
998
Observed water surface
Stream bottom
SECTION 5
STATION 5+30
DEER CREEK
NEAR
ANYWHERE, MONTANA
-0
0+00
0+10
0+20
0+30
0+40
0+50
0+60
0+70
0+80
0+90

Figure 4


Sec. No. 1
Sta. 0+00
Sec. No. 2
Sta. 0+65
Sec. No. 3
Sta. 1+65
Sec. No. 4
Sta. 2+65
Sec. No. 5
Sta. 3+30
Sec. No. 6
Sta. 3+50
Sec. No. 7
Sta. 5+00
Thalweg
Observed water surface profile
ELEVATION IN FEET
5400
5300
5200
5100
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
4000
ELEVATION IN FEET
Figure 5
WATER SURFACE PROFILES
DEER CREEK
NEAR
ANYWHERE, MONTANA

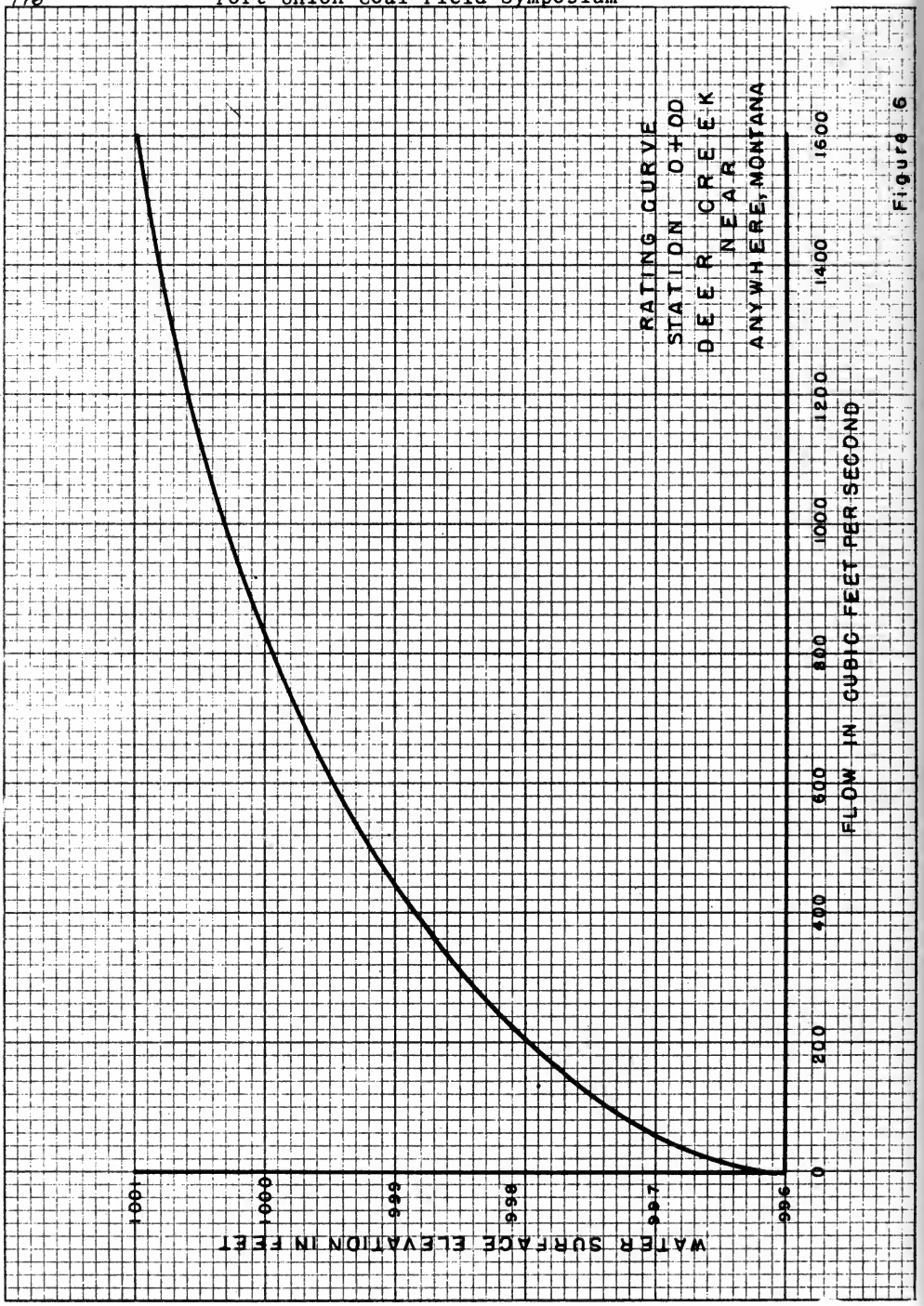

RATING CURVE
STATION 0+00
DEER CREEK
NEAR
ANYWHERE, MONTANA
WATER SURFACE ELEVATION IN FEET
1001
1000
999
998
997
996
0
200
400
600
800
1000
1200
1400
1600
FLOW IN CUBIC FEET PER SECOND

Figure 6

in stream characteristics without having to make many field observations and measurements at different flows.

Tables 1 though 6 are examples of the typical output data set from a WSP computer run. These data, of course, vary from application to application and are a summary of the total output.

GLOSSARY OF TERMS

Station - an expression of distance, measured in feet, between cross sections. This distance is normally measured along the line of flow or along the thalweg. Example see Figure 2; cross section No. 1, Sta. 0+00 and cross section No. 2, Sta. 0+85; the distance between these cross sections is 85 feet.

Thalweg - the thalweg is the low part or deepest part in a channel.

"n" factor - "n" factor is the roughness coefficient of the channel or parts of the channel. The roughness coefficient is an expression of resistance to flow caused by the streambed.

Energy balance - computation performed by the computer to balance flow and velocity between cross sections to observed water surface elevations.

Stream segment or section - portion of the stream being studied (See Figure 1).

Cross section - transect or section taken at right angles to the flow in the stream. (Figure 3.)

Control section - a section in the stream that controls the flow and water surface elevation. This control can be exerted by a riffle, channel constriction, diversion dam, etc.

Cross section segment - a portion of the cross section isolated by bottom type, roughness, or for particular study.

RULES TO FOLLOW WHEN TAKING FIELD DATA

Cross sections - Cross section locations should be marked first, the minimum number of cross sections necessary for reliable computation is four.

Flow measurements - the flow measurement should be made when the river or stream is stable and not influenced by a rising or dropping flow. The water surface elevations at the other cross sections should be marked just before or after the flow measurement is made.

Distance between cross sections - the distance between cross sections or the number of cross sections depends on the river being studied. A good rule is to take as many cross sections as needed to describe the stream. Measurements on stream bends or curves should include the outside and inside streambank distances.

Cross section extension - cross sections should extend up

the overbank far enough to properly describe this area for high flows, if the investigator is interested in effects of high flows.

Bottom type description - the bottom type should be described as follows:

Vegetation - weeds, moss, etc.
Sand, Silt, Clay - particles less than 0.1 inch
Gravel - rocks 0.1 to 3 inches in diameter
Cobbles (rubble) - rocks 3 to 12 inches in diameter
Boulders - rocks over 12 inches in diameter
Bedrock - large mass of solid rock.

Examples of WSP OUTPUT

Table 1

SUMMARY OF PROFILE DATA

Discharge Table

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

DISCHARGE	BEGINNING ELEVATION	ROUGHNESS MODIFIERS FOR OVERBANK	ROUGHNESS MODIFIERS FOR MAIN CHANNEL	ESTIMATED BEGINNING HYDRAULIC GRADIENT
25.	REDUNDANT	1.00	1.00	.01034
40.	REDUNDANT	1.00	1.00	.01034
50.	REDUNDANT	1.00	1.00	.01034
60.	REDUNDANT	1.00	1.00	.01034
77.	992.10	1.00	1.00	REDUNDANT
90.	REDUNDANT	1.00	1.00	.01034
100.	REDUNDANT	1.00	1.00	.01034
125.	REDUNDANT	1.00	1.00	.01034
150.	REDUNDANT	1.00	1.00	.01034
200.	REDUNDANT	1.00	1.00	.01034
250.	REDUNDANT	1.00	1.00	.01034
300.	REDUNDANT	1.00	1.00	.01034
400.	REDUNDANT	1.00	1.00	.01034
500.	REDUNDANT	1.00	1.00	.01034

SUMMARY OF OPTION AND COORDINATE DATA

Cross Section Data

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

STATION	NUMBER OF ROUGHNESS SEGMENTS IN SECTION	ELEVATION OF SEDIMENT DELTA	ELEVATION OF OBSERVED PROFILE	INCREMENTAL DISCHARGE
82.	4	0.0	0.0	0.

NUMBER OF COORDINATE PAIRS = 17
OPTION PARAMETERS OF ZERO INDICATE A REDUNDANCY

RIGHT MOST COORDINATE	ROUGHNESS COEFFCIENT	REACH LENGTH OF CENTROID
8.	.055	29.
31.	-.035	29.
53.	.035	29.
61.	.055	29.

X COORDINATES	0.0	8.0	9.0	10.0	11.0	12.0	16.0	21.0	25.0	28.0
Y COORDINATES	1001.6	999.0	998.7	997.9	997.8	997.1	995.9	995.3	995.7	996.4
X COORDINATES	31.0	33.0	41.0	45.0	50.0	53.0	61.0			
Y COORDINATES	996.8	997.3	997.2	996.9	997.3	998.3	1001.0			

Table 2

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF MAIN CHANNEL DISTANCES

STATION	DISTANCE BETWEEN CROSS SECTIONS	CUMULATIVE DISTANCE
0.		0.
	48.	
48.		48.
	5.	
53.		53.
	29.	
82.		82.
	115.	
197.		197.
	104.	
301.		301.

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF ROUGHNESS COEFFICIENTS

STATION				
0.	.050	-.040	.050	
48.	.055	-.045	.045	.055
53.	.050	-.040	.040	.055
82.	.055	-.035	.035	.055
197.	.050	-.045	.060	
301.	.055	-.050	.060	

Table 3 Flow Data

PAGE NO. 5

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

STATION 0 + 82 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 995.3 THALWEG SLOPE .0103

COMPUTATION LINE HF1 = .52 HV1 = .54 AVG OVERBANK REACHES - LEFT = 29. RIGHT = 29.

LENGTH OF CENTROID	CONVEYANCE AREAS	TOP WIDTHS	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES	DISCHARGES
29	42	21	1.9	-.03500	2808	2.70	116
29	20	21	1.0	.03500	853	1.68	34
SUM OR AVG	62	42			3661	2.50	150

THIS SECTION HAS 4 ROUGHNESS SEGMENT OR SEGMENTS. 2 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .05 HV2= .10 SF VOIDED TOTAL HEAD= .78 CRIT. FLOW= 398 W.S. ELEV.= 998.18

• • •

STATION 0 + 82 ENGLISH UNITS ASSUMED ELEV. 0.00 THALWEG ELEV. 995.3 THALWEG SLOPE .0103

COMPUTATION LINE HF1 = .43 HV1 = .53 AVG OVERBANK REACHES - LEFT = 29. RIGHT = 29.

LENGTH OF CENTROID	CONVEYANCE AREAS	TOP WIDTHS	HYDRAULIC RADII	ROUGHNESS COEFFICIENTS	CONVEYANCE FACTORS	VELOCITIES	DISCHARGES
29	46	21	2.1	-.03500	3272	3.14	148
29	25	22	1.1	.03500	1164	2.08	52
29	0	0	.0	.05500	0	.13	0
SUM OR AVG	71	43			4436	2.90	200

THIS SECTION HAS 4 ROUGHNESS SEGMENT OR SEGMENTS. 3 SEGMENT OR SEGMENTS USED FOR THIS DISCHARGE
COMPUTATION LINE HF2= .06 HV2= .13 SF VOIDED TOTAL HEAD= .69 CRIT. FLOW= 486 W.S. ELEV.= 998.38

• • •

Table 4

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF WATER SURFACE ELEVATIONS

		FLOWS IN CFS									
		25. 300.	40. 400.	50. 500.	60.	77.	90.	100.	125.	150.	200.	250.
STATION	THALWEG	WATER SURFACE ELEVATIONS----FEET										
0.	990.6	991.6 993.3	991.8 993.6	991.9 994.0	992.0	992.1	992.2	992.3	992.4	992.6	992.8	993.0
48.	991.0	992.2 993.9	992.4 994.3	992.5 994.7	992.6	992.8	992.9	992.9	993.1	993.2	993.5	993.7
53.	995.0	996.1 998.1	996.3 998.4	996.5 998.6	996.6	996.8	996.9	997.0	997.3	997.4	997.7	997.9
82.	995.3	996.9 998.8	997.1 999.2	997.3 999.6	997.4	997.6	997.8	997.9	998.0	998.2	998.4	998.6
197.	998.8	999.7 1001.2	999.9 1001.6	1000.0 1001.9	1000.0	1000.2	1000.3	1000.3	1000.4	1000.6	1000.8	1001.0
301.	1004.4	1005.5 1006.6	1005.3 1007.0	1005.4 1007.3	1005.5	1005.6	1005.7	1005.7	1005.9	1006.0	1006.2	1006.4

Table 5

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF MAIN CHANNEL DISCHARGES AND VELOCITIES

	FLOWS IN CFS									
	25. 300.	40. 400.	50. 500.	60.	77.	90.	100.	125.	150.	200.	250.
STATION	DISCHARGES IN CFS -/- VELOCITIES IN FT./SEC.										
0.	25. 2.40	40. 2.77	50. 2.96	60. 3.15	77. 3.43	90. 3.59	100. 3.74	125. 4.06	150. 4.35	199. 4.84	249. 5.25
	299. 5.60	399. 6.20	499. 6.70								
48.	22. 3.11	31. 3.50	37. 3.71	43. 3.90	52. 4.17	58. 4.33	64. 4.46	76. 4.75	88. 4.99	110. 5.36	132. 5.64
	152. 5.86	189. 6.14	220. 6.21								
53.	25. 4.31	40. 4.84	50. 5.14	60. 5.38	77. 5.70	90. 6.09	100. 6.17	120. 5.55	141. 6.09	172. 6.20	205. 6.66
	237. 7.06	297. 7.73	356. 8.27								
82.	25. 1.50	40. 1.87	49. 2.03	57. 2.10	68. 2.18	76. 2.15	82. 2.21	101. 2.63	116. 2.70	148. 3.14	177. 3.38
	205. 3.58	262. 3.93	317. 4.25								
197.	25. 3.64	40. 4.08	50. 4.36	60. 4.60	77. 4.91	90. 5.06	100. 5.23	125. 5.62	150. 5.94	200. 6.32	250. 6.73
	300. 7.07	400. 7.63	500. 8.11								
301.	25. 1.93	40. 3.94	50. 4.25	60. 4.52	77. 4.91	90. 5.17	100. 5.35	125. 5.57	150. 5.90	200. 6.47	250. 6.94
	300. 7.34	400. 8.02	500. 8.59								

Table 6

TOM MINER CREEK -- T7S R7E SEC30 -- TRIBUTARY TO YELLOWSTONE RIVER
SOUTH OF LIVINGSTON, MONTANA

TABLE OF IN CHANNEL TRACTIVE FORCES

	FLOWS IN CFS										
	25. 300.	40. 400.	50. 500.	60.	77.	90.	100.	125.	150.	200.	250.
STATION	TRACTIVE FORCE---LBS/SQ. FT.										
0.	.3274 1.1567	.4047 1.3502	.4463 1.5189	.4904	.5594	.5984	.6348	.7199	.7971	.9251	1.0469
48.	.6907 1.7277	.7973 1.8128	.8765 1.8119	.9620	1.0554	1.0880	1.1737	1.2757	1.3776	1.5146	1.6477
53.	1.0395 1.8223	1.2055 2.0752	1.3044 2.3024	1.3894	1.4928	1.6774	1.7080	1.3043	1.5368	1.4915	1.6638
82.	.0813 .3305	.1200 .3860	.1337 .4320	.1406	.1425	.1370	.1429	.2012	.2060	.2683	.3011
197.	1.0538 2.5116	1.2245 2.7866	1.3418 3.0147	1.4382	1.5797	1.6255	1.7001	1.8755	2.0233	2.1600	2.3483
301.	.3194 3.2894	1.4443 3.7175	1.6042 4.0654	1.7484	1.9527	2.0972	2.1960	2.2560	2.4415	2.7644	3.0426

A REMOTE SENSING STUDY OF SEDIMENT IN THE CLARKS FORK, YELLOWSTONE RIVER

John W. Keys III, James F. Ruff,
and Morris M. Skinner*

INTRODUCTION

In considering water resources of the Fort Union coal area, sediment carried by runoff in streams of the region must be evaluated. This evaluation is necessary to determine the proper use, and the impact of that use, of water from those streams. The study of sediment in the Clarks Fork Yellowstone River is an example of a procedure for locating sediment sources and determining the relative magnitude of sediment problems being experienced in a basin.

Background

Historically, the Clarks Fork Yellowstone River has discharged heavy loads of sediment annually into the Yellowstone River (5,8). Transporting this material from the basin has destroyed much of the river's potential for trout fishing and recreation; has represented a substantial loss of topsoil to the agriculturalists; and has created numerous problems for public water supplies. The soils, topography, rainfall pattern, land use, and irrigation practices of the basin were assumed to be the principal factors causing sediment movement into the river and sediment deposition in some reaches of the stream channel.

In an effort to define sediment problems and their causes in the Clarks Fork Yellowstone River, the 1971 Montana State Legislature established the Clarks Fork Siltation Study Commmittee and gave it the responsibility of preparing a report on its findings for the 1973 legislative session (1971 House Resolution No. 24). Composed of representatives from several state agencies, Federal agencies, and various county and local organizations, the Committee began investigation of the basin during the summer of 1971. In early considerations of its investigative procedures, the use of remote sensing techniques to aid in the study was examined and the Bureau of Reclamation agreed to undertake such an investigation as part of its participation in the program.

Basin Characteristics

The Clarks Fork Yellowstone River is located in south-central Montana and northwestern Wyoming. The river drains an area of approximately 2,800 square miles, extending from the northeast corner of Yellowstone National Park northeastward, to its confluence with the Yellowstone River near Laurel, Montana. The major tributary of the Clarks Fork Yellowstone River is Rock Creek, which has a drainage of about 570 square miles.

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The Clarks Fork Yellowstone River Basin has a wide variety of physical features, beginning among the lofty peaks and highly glaciated plateaus of the Absaroka Mountain Range and ending in the plains of the Yellowstone River Valley. Because of the ranges in elevation, topography, and precipitation present in the Clarks Fork Yellowstone River Basin, soil types are quite varied, depending upon the location of sites within the basin (2). Generally, there are four main soil groups in the drainage area: (a) Loamy, well drained soils of the flood plains and narrow valley, (b) deep, moderately deep, and shallow clayey soils of the shale and sandstone uplands, (c) deep and moderately deep loamy soils of the outwash terraces and fans, and (d) steep slopes of shallow to deep loamy soils of the mountains.

Land use in the Clarks Fork Yellowstone River Basin is primarily agricultural with nearly 70 percent of the total land area devoted to cropland, pasture, and range. The forested areas of the basin are primarily in the mountain areas and the parks of the foothills. The land above timberline in the Beartooth Plateau has an Alpine tundra-type vegetation.

Scope of Investigation

The basic purposes of the study were: (a) To locate the points at which sediment loads are discharged into the river, (b) to estimate the relative magnitude of sediment concentrations in the tributary flows as compared to the river, and (c) to show the usefulness of aerial remote sensing techniques (color infrared photography and thermal imagery) in monitoring and studying sediment movements in a river system.

The basic procedure for the investigation of sediment in the Clarks Fork Yellowstone River involved four main phases of operation: (a) a reconnaissance of the basin to outline the problems to be investigated and general conditions of the area, (b) the ground-truth data program to collect physical information about the study area to relate to the photographs and imagery, (c) aerial flights to obtain the color infrared photographs and thermal infrared imagery to cover the areas under investigation, and (d) the interpretation and analysis of the data.

RECONNAISSANCE

An initial step in the sediment study was to make several reconnaissance surveys of the basin to review the study area, to determine the nature of the sediment problems in the river, and to outline a plan of study for the proposed investigation. These surveys were conducted by the Clarks Fork Siltation Study Committee during the fall of 1971 and the spring and summer of 1972, and involved both aerial and ground surveillance (1).

An aerial reconnaissance of the Clarks Fork Yellowstone River Basin was conducted by the Clarks Fork Siltation Study Committee on September 13, 1972, and covered the main stem of the river and its tributaries in Montana. Results of that survey showed the river carried a heavy sediment load at its mouth, but was relatively clear at the Montana-Wyoming state line.

The aerial reconnaissance flights were most useful in observing sediment problems and conditions in the Clarks Fork Yellowstone River Basin. To better define the relationship between these principles, several ground surveys were conducted.

Ground surveys of the Clarks Fork Yellowstone River Basin, although limited, were directed toward observing soil and ground-cover conditions in several subbasins of the drainage area and observing irrigation practices in the flood plain of the river. Considering the large area of the basin to be covered by this investigation and the amount of time involved in detailed ground surveys, an effort was made to find a suitable method for studying sediment problems in the whole Clarks Fork Basin in a reasonable length of time.

In considering methods for studying sediment problems in the Clarks Fork Yellowstone River and the areas for concentrated investigation, a series of aerial color infrared and normal color (ektachrome) photographs covering headwaters of the basin were obtained from the National Aeronautics and Space Administration. With both high-level and low-level imagery (taken from 60,000 feet and 7,000 feet above mean sea level, respectively), an overall view of the upper drainage area was made possible and the practicality of remote sensing for investigation of the area was demonstrated.

From the information gained during reconnaissance of the Clarks Fork Basin and a review of present remote sensing technology, aerial infrared photography and thermal imagery were selected to study sediment problems in the river. A ground-truth data program was then established to gather the necessary information to adequately define relationships between physical conditions of the basin and the photographs and imagery.

GROUND-TRUTH DATA PROGRAM

The ground-truth data program was designed to provide information on flow conditions of the river and its tributaries while remote sensing flights were in progress. These data were obtained for the main stem of the river and its major tributaries from the confluence with the Yellowstone River near Laurel, Montana, to the mouth of Clarks Fork Yellowstone River Canyon in Wyoming.

The primary data collected during this ground-truth program were sediment samples, surface-water temperatures, and water depths. The sediment samples were analyzed for turbidity and sediment concentration. Water temperature cross sections were also obtained at five locations along the main stem of the Clarks Fork Yellowstone River. A detailed description of each sampling point, including the data collected, is given in Reference 4.

Prior to the remote sensing flights, the storm of August 13-15, 1972, deposited heavy amounts of rain in the southwestern portion of the basin, with some local flooding occurring near Cooke City, Montana. It was estimated that flooding had subsided at the time of the remote sensing flights which were made on August 18, 1972. Stream flows, recorded at United States Geological Survey gaging stations in Clarks Fork Yellowstone

River Basin on the day of the aerial remote sensing flights, are given in Table 1 along with 10-year average flows for August. Generally, these flows were higher than normal for this time of the year, but they reflected the above-normal precipitation in the area for the entire summer.

AIRBORNE DATA

Color infrared photography, with 60 percent endlap for stereoscopic viewing, and thermal infrared imagery were obtained for the rivers and adjacent flood plains. The photography provided coverage of a strip of the flood plain approximately 1 1/2 miles wide for Red Lodge Creek, Rock Creek, and the lower section of the Clarks Fork Yellowstone River. Photographic coverage of the upper 36 miles of the Clarks Fork Yellowstone River provided a strip approximately 2 1/2 miles wide. Interpretation of the data was based upon, and limited to, this coverage.

The aerial photography for the Clarks Fork Yellowstone River, Red Lodge, and Rock Creeks was taken on August 18, 1972, between 10:24 a.m. and 11:45 a.m. Mountain Daylight Time (MDT). The weather over the sites was generally clear with a few localized scattered clouds in the vicinity of the confluence of the Clarks Fork Yellowstone River and the Yellowstone River. Photographs of the Clarks Fork Yellowstone River, from the confluence with the Yellowstone River to the mouth of the canyon, were taken approximately 5,000 feet above the mean terrain, giving a photographic scale of approximately 1:10,000. Photographs of the Clarks Fork Yellowstone River above the mouth of the canyon were taken at an altitude of approximately 8,500 feet above the mean terrain, giving a photographic scale of about 1:17,000. Photographs of Rock Creek and Red Lodge Creek also were taken at a scale of approximately 1:10,000.

The photography was taken with a precision mapping camera using a nominal 6-inch lens. The system included filters, a navigation sight, and a universal mount. The camera system produced a 9-inch by 9-inch photograph with minimum distortion and high resolution. The infrared film was processed to a positive transparency for analysis on a light table.

Thermal infrared imagery of the Clarks Fork Yellowstone River, Rock Creek, and Red Lodge Creek was collected by the Forest Service, United States Department of Agriculture, stationed at Missoula, Montana. The thermal infrared imagery was obtained on August 18, 1972, between 6:20 a.m. and 7:10 a.m. MDT, from an altitude of approximately 3,000 feet above the mean terrain. The imagery was recorded on a 3 1/2-inch wide strip-film format, providing a negative transparency.

DATA ANALYSIS

Three distinct portions of the electromagnetic energy spectrum are of interest in this remote sensing study: (a) The visible portion, having wavelengths from 0.4 μ.m.-0.7 μ.m., (b) the photographic infrared portion, from 0.7 μ.m.-0.9 μ.m., and (c) the thermal infrared portion, from 8 μ.m.-14 μ.m.

Color infrared film is sensitive to electromagnetic energy

Table 1 - Flow Rates

United States Geological Survey Station Number (1)	Stream (2)	Flow, in Cubic Feet Per Second (3)	10-Yr. Average August Flow, in Cubic Feet Per Second (4)
6207500	Clarks Fork Yellowstone River near Belfry	1,050	742
6208800	Clarks Fork Yellowstone River near Silesia	1,150	770
6209500	Rock Creek near Red Lodge	370	300
6211000	Red Lodge Creek above Cooney Reservoir	58	41
6212500	Red Lodge Creek below Cooney Reservoir	127	155

having wavelengths from 0.4 μ.m.-0.9 μ.m. It contains three layers of emulsion which are sensitized to repond to wavelength bands corresponding to green, red, and the photographic infrared. All three emulsions are sensitive to blue light and therefore a minus-blue filter (such as Kodak Wratten 12 or 15 filter) is used to eliminate the wavelengths below 0.5 μ.m. Through a subtractive color process this film produces a "false" color image of the scene in which green appears blue, red appears green, and photographic infrared appears red. The infrared sensitive color film originally was designed for military applications of camouflage detection. It has been used also for forest and citrus tree surveys to identify diseased foliage (3). Recently, the film has been used extensively by Colorado State University for river studies (6,7). The color infrared film has been found to be very effective for monitoring sediment transport processes in rivers. Small differences in suspended material concentration in water manifest a color difference on the color infrared film (6).

The longer wavelength portion of the electromagnetic energy spectrum, from 8 μ.m.-14 μ.m., is thermal or emitted radiation. To record this portion of the spectrum the radiation must be focused on a special detector such as Mercury-Cadmium-Telluride or Mercury-doped Germanium. The transduced signal is used to modulate a light source which, in turn, is used to expose a black and white film strip. The gray level of the resulting imagery is proportional to the emissivity and temperature of the object.

The gray tones on the thermal imagery provide a qualitative indication of water surface temperatures. The gray tones of other terrain scenes are recorded in accordance with the value of their corresponding emissivities and temperatures. Water has an emissivity close to unity, but soil and vegetation exhibit values slightly less than unity.

Interpretive Keys

The following interpretive keys were used to identify the

localized inflows, tributaries, and potential tributaries which would be sources of sediment for the river.

Color.--Color is the primary key to identifying sources of sediment-laden water flowing into the Clarks Fork Yellowstone River. Clear water inflows appear dark blue (black in the case of deep water) on color infrared film. Change of color in the water corresponds with a change in near surface suspended concentration or change in sediment type or both. Green vegetation, which appears a bright red on color infrared film, is also a key for identifying ditches or potential drainage way.

Topographic Relief.--Stereoscopic viewing of photography provides the three-dimensional relief necessary to identify small catchments and erosion patterns and to judge the slope and topography of the land.

Pattern, Shape, and Texture.--Irrigated farmlands and row crops are identified readily by patterns, alinements, colors, and textures. Upland areas have characteristic colors, erosion patterns, and shapes.

Temperature/Emissivity.--Interpretation of the thermal infrared imagery is based upon a judgment of gray levels and the temperature/emissivity characteristics of the scene.

Color infrared photography effectively detects small changes in low concentrations of suspended particles in water and enhances the change by a color difference. Sufficient research to determine if the cause of the color difference is the change in turbidity level or suspended solids concentrations has not been accomplished. However, for this study on the Clarks Fork Yellowstone River, it was found that the suspended solids concentration and the turbidity level appear to vary linearly within the normal scatter associated with field sampling procedures. Determination of a quantitative relationship between turbidity or sediment concentration and water color observed on the color infrared film was not attempted in this study.

Interpretation

Primary interpretation of both the color infrared photography and the thermal infrared imagery was based on the interpreter's visual acuity. The inflows to the river were identified using the interpretative keys listed previously. The data were analyzed by viewing both the color infrared positive transparency film and the thermal infrared imagery (processed to a negative transparency) on a light table fitted with a large magnifying reading glass. The interpreter scanned the photographs and imagery to locate points of inflow which were detectable as sediment plumes or temperature plumes in the river. Drainage patterns delineated by vegetation or erosion areas, or both, identified other potential sources of sediment inflow. The most obvious locations were found and described by this scanning process. Steropairs of photography were then viewed to identify drainage relief, which was not obvious in the initial overview. Magnification of the image through a sterescope allowed the interpreter to view characteristics at the bank line and in the gully and ditch bottoms necessary to determine if they contained

water. Ditches, gullies, and tributaries were traced through their respective drainage basins to the limits of the photographic coverage.

The color of the water was used to estimate if the suspended sediment concentration of the inflow was greater or less than that of the river. The interpreter identified the inflow or potential inflow and described the relative suspended material concentration within the discrete photographic field of view.

Examples of the Clarks Fork Yellowstone River and several tributary inflows are given in the following illustrations. All photographs in this paper are black and white reproductions of the color infrared photographs. Due to this reproduction procedure, the enhancement of the sediment concentration differences observed on the original color infrared transparency is reduced.

The confluence of the Clarks Fork Yellowstone River and the Yellowstone River is shown in Figure 1. Samples of suspended sediment indicated 35 ppm (21 JTU) at Point YA upstream from the confluence on the Yellowstone; 85 ppm (39 JTU) at Point YB downstream from the confluence, and 145 ppm (75 JTU) at Point 1 on the Clarks Fork Yellowstone River upstream from the confluence. On the original color infrared film the higher sediment concentration is clearly delineated by the lighter, blue-gray color of the Clarks Fork Yellowstone River versus the darker blue of the Yellowstone River. Little mixing of the river waters occurs immediately downstream from the confluence, as can be seen from the distinct plume. The suspended sediment sample obtained at Point YB was in the mixing zone of the Clarks Fork Yellowstone River.

The confluence of Rock Creek and the Clarks Fork Yellowstone River is shown in Figure 2. The dark tone of the water in Rock Creek has a lower turbidity (11 JTU) than the Clarks Fork (70 JTU).

The thermal infrared imagery of the confluence of Bennett Creek and the Clarks Fork is shown in Figure 3. Bennett Creek is designated BC, and the Clarks Fork Yellowstone River CF. The colder water of Bennett Creek, the plume, and the mixing zone are clearly identified by the darker tone on the imagery. The plume can be observed on the imagery for approximately 1,500 feet downstream from the confluence.

This remote sensing study of sediment in the Clarks Fork Yellowstone River resulted in the identification and tabulation of 106 contributing sources of sediment, real and potential, to the river. Thirty-seven inflows to the main stem and four inflows to Rock Creek and Red Lodge Creek had a higher turbidity than the receiving water at their respective points of entry. Sixteen inflows to the Clarks Fork and four inflows to Rock Creek and Red Lodge Creek had lower turbidity. Forty-six dry sites were identified as entering the Clarks Fork and nine entered Rock Creek and Red Lodge Creek.

The relative turbidity of the Clarks Fork Yellowstone River generally increased from about 30 JTU at the mouth of Clarks Fork Canyon in Wyoming to about 75 JTU at the Yellowstone River

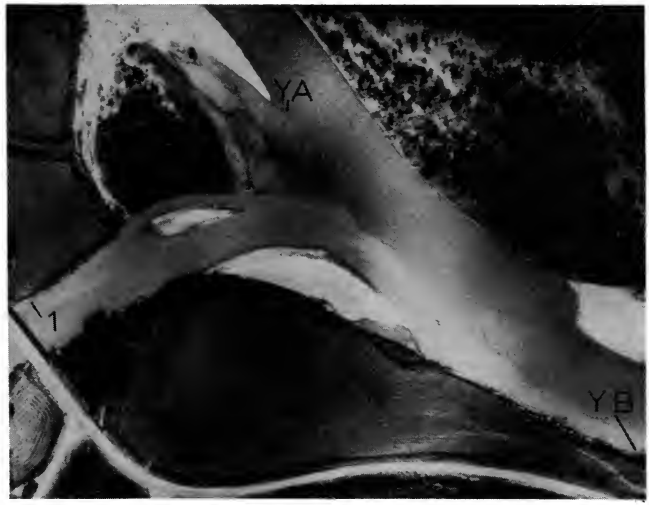

Figure 1 - Confluence of Clarks Fork Yellowstone River and Yellowstone River.

Figure 2 - Confluence of Rock Creek and Clarks Fork Yellowstone River.

Figure 3 - Thermal Infrared Imagery of Confluence of Bennett Creek and Clarks Fork Yellowstone River.

confluence near Laurel, Montana. Over this reach an increase in turbidity in the downstream direction was observed on the color infrared photographs.

CONCLUSIONS

From results of this investigation, the following conclusions were drawn on sediment in the Clarks Fork Yellowstone River:

1. Only a small amount of active erosion of surface material is being caused by irrigation;

2. The majority of suspended material being transported by the river is being obtained from the bed and banks of the river and its tributaries;

3. The erodible bed and bank materials were probably deposited in the river as a result of the highly erosive soils of the basin and runoff from high intensity storms of the area; and

4. Irrigation return flows contribute to the sediment problems of the river by providing the water to carry the material.

Support of these conclusions by the remote sensing investigation was not complete since most of the imagery covered only the portion of the drainage basin adjacent to the river. In areas where small catchments exist on the sideslopes of the valley, the exact catchment area was delineated and sediment sources readily identified. The ground-truth data program supplied some verification of this material.

Results of this study also indicate that aerial color

infrared photography and thermal infrared imagery are practical tools for locating and identifying existing and potentional inflows of sediment-laden water to a river system. Data can be obtained rapidly accurately.

Color infrared photography effectively detects small changes in low concentrations of suspended particles in water and enhances the change by a color difference. Interpretation of the color infrared photography provides a means of qualitatively assessing the suspended material concentration of the river system. Thermal infrared imagery provides an indication of temperature differences of the river and tributaries. An interpreter can evaluate the ground-truth information more accurately and can locate ground sampling sites that are representative of the phenomenon of interest. Field survey work can be performed with greater efficiency and at less cost because of prior knowledge about drainage locations, terrain and accessibility.

Each of the above two systems provides information relative to the river system. Color infrared photography is best for identifying sediment concentration differences. Thermal infrared imagery provides an indication of the relative temperatuare of the scene. Together they provide a unique, quasi-synoptic view of the sediment transport process in a river system. It should be recognized, however, that a flight of this kind is a "one-shot" view of the river system characteristics. Only the conditions for a single set of flow relationships among the river and its tributaries were observed, thus the overall picture would change with different flow conditions. For example, turbidities, temperatures, and sediment concentrations would vary in unique patterns for different flow conditions resulting in changing spectral signatures sensed by the remote detecting systems. Research should be continued in attempts to quantify these three factors by improving the interpretive techniques of analyzing data collected by remote sensors.

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DEVELOPMENT AND ANALYSIS OF A GENERAL STREAM SIMULATION TECHNIQUE

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INTRODUCTION

An ecosystem model is being developed to be used as a tool in the study of aquatic streams. The initial work was undertaken by the aquatic section of the Desert Biome, International Biological Program, and at present is being further developed between this group and members from the Utah Cooperative Fishery Unit with funding from the Central Utah Project, Bureau of Reclamation. The model is a general, abstract, dynamic, nonlinear, computer simulation, in which the ecosystem is presently envisaged as a horizontally homogeneous stretch of water. It is general in the sense that specific components of the ecosystem modeled are not specified by the model, but are left to be specified by the user at execution time, along with a series of switches and parameters that control these components. With this control it becomes unnecessary to describe separately the processes in which each state variable is involved. Instead, switches and parameters are set in a manner that allows only processes relevant to a particular state variable to occur.

At the present time the main state variables being modeled are the quantities of the different organic constituents which make up the plants, animals, heterotrophic microorganisms, detritus, and the dissolved component of the water, the inorganic constituents, either dissolved or in a particulate state, and certain physical characteristics, such as depth and velocity. Exogenous variables include the materials entering the ecosystem from upstream drift, tributaries, overland flow and from the atmosphere. Also included are precipitation, temperature, solar radiation, daylength, and discharge. Materials may exit from the system through downstream flow, by way of withdrawals for irrigation, or in the case of water, by evaporation. Those variables that represent materials which leave the system as downstream flow may be saved and used as input in the case where more than one stretch of stream is to be simulated.

The computer representation of the model is written in FORTRAN IV, using difference equations over a time step of one day. If the approximation by difference equations over this time step leads to negative values of an essentially non-negative variable, the program reduces the time unit as required.

Further information concerning the model is available in reports by Wlosinski (3) and Stalnaker (2).

PROCESSES MODELED

Figure 1 is a simplified diagram of the energy flow within the model. It is simplified because each of the variables in the figure may be represented in the model as a series of variables

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broken down by taxonomic or size classes, each with as many flows as represented in the figure. Each of the major groups is also broken down to elemental constituents, each with a flow similar to Figure 1. To gain a better understanding of the processes and factors regulating fluxes for the major groups modeled, three other figures are presented. Figure 2 refers to the plant processes, Figure 3 for the animals and Figure 4 for the decomposers.

Abiotic section

It is assumed that all incoming material, be it water, organic or inorganic constituents, enter the ecosystem at the head of the stretch being modeled, and that uniform mixing takes place so that concentrations of dissolved and suspended materials through the system remain constant over the time unit of simulation.

Water in the system is incremented from upstream flow, from tributary flow, and from precipitation and overland flow. Decrements occur as water flows downstream, is withdrawn for irrigation, or is evaporated. All of these figures are input data except for water flowing downstream, which is calculated taking into account the above factors as well as the average amount of water in the system for the present as well as previous time periods. Water contains dissolved constituents, and these are tracked as they enter the system through the same four sources as water. All particulate detritus categories, both organic and inorganic, are accounted for as they enter the system from upstream, tributaries and overland flow as well as falling into the system from the atmosphere. Live material, or those constituents which make up the plants, animals and heterotrophic microorganisms can enter the system from upstream or tributary flow.

Coagulation of dissolved organic carbon and its associated energy in the water column takes place at a constant rate with the products incrementing the finest organic detrital category specified. Organic and inorganic detritus may be scoured or deposited, with this occurring as a function of water velocity. Dissolved constituents pass between the water column and the interstitial water, this occurring as a function of the number of times the water in the column has been exchanged in a time period and as a measure of the thickness of the benthos and the constituent concentration difference between the two areas.

Plant section

Photosynthesis depends above all on the radiation reaching the plant. The mean radiation intensity at the water surface for the daylight hours is an exogenous variable, with this intensity being scaled down to the average depth of a particular plant group. Attenuation of the radiation is due to absorption by the water column, dissolved organic and inorganic constituents, organic and inorganic detritus, and any plant at an average depth shallower than the plant under consideration. Self-shading is also provided for, with half the biomass of the same species (or any other species at the same depth) being included in the shading material.

Besides the radiation, photosynthesis also is affected by

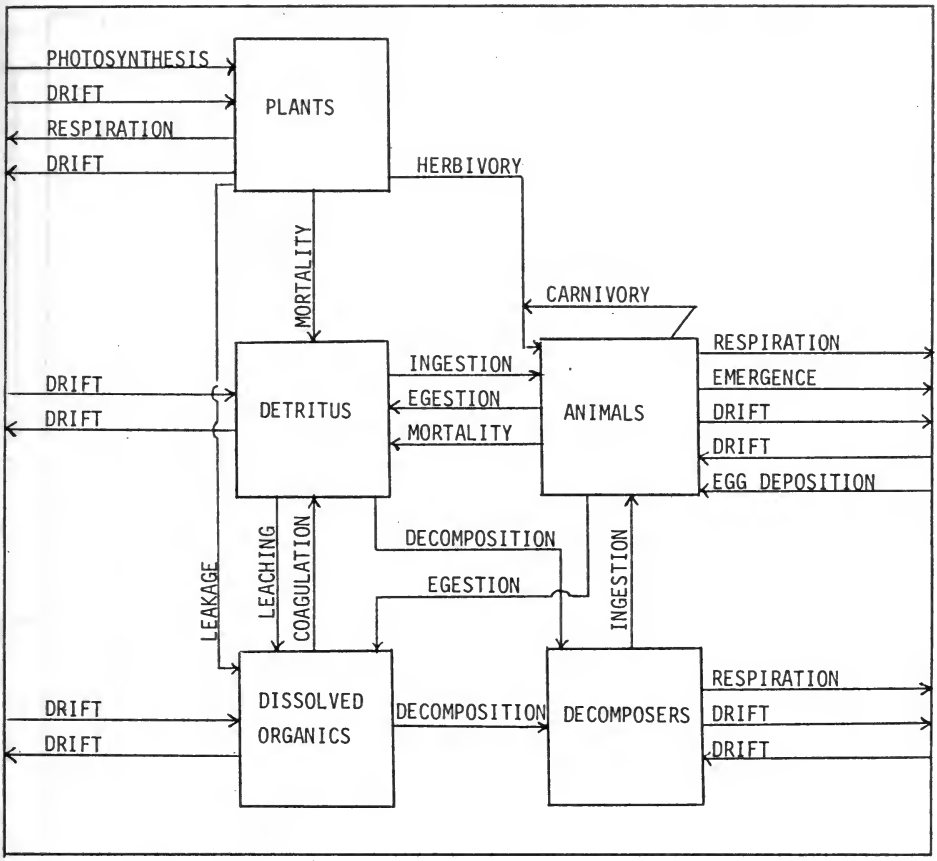

Figure 1. A simplified diagram of the energy flow within the general stream ecosystem model.

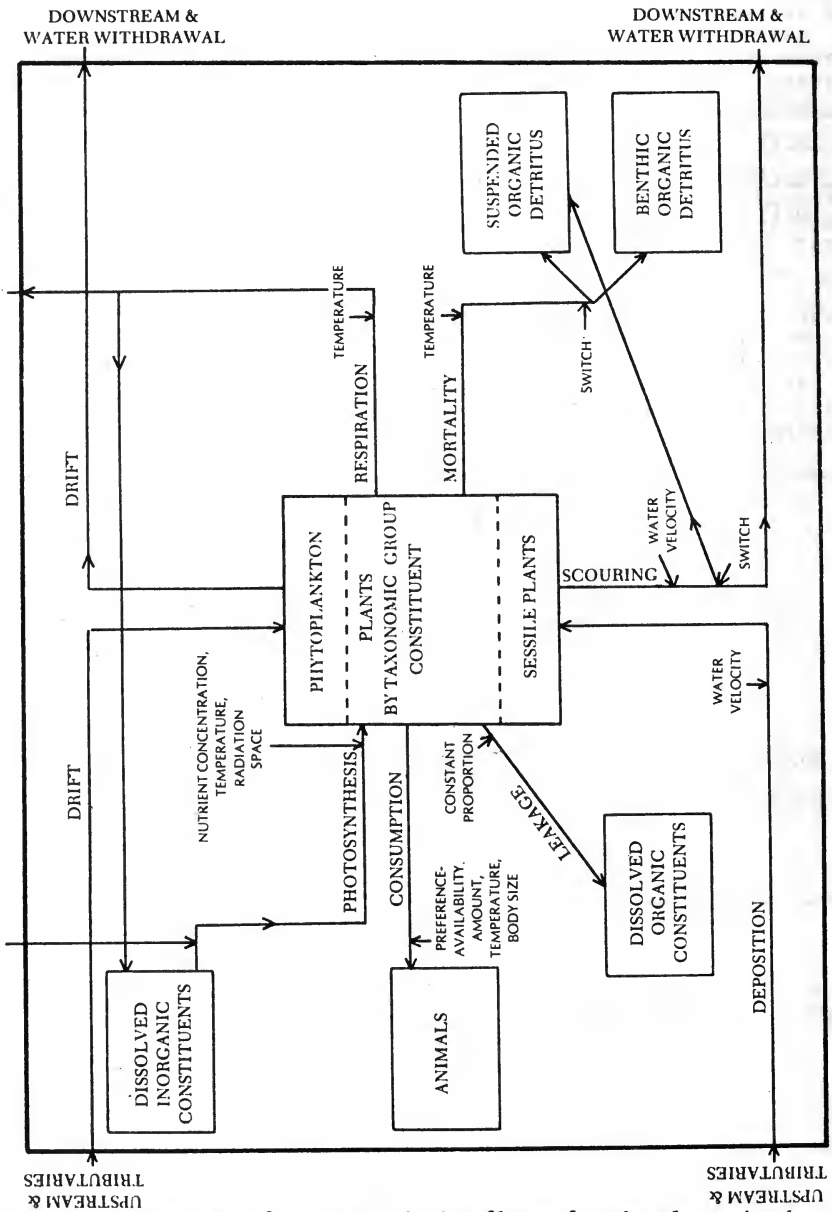

Figure 2. Processes and factors regulating fluxes for the plants in the general stream model.

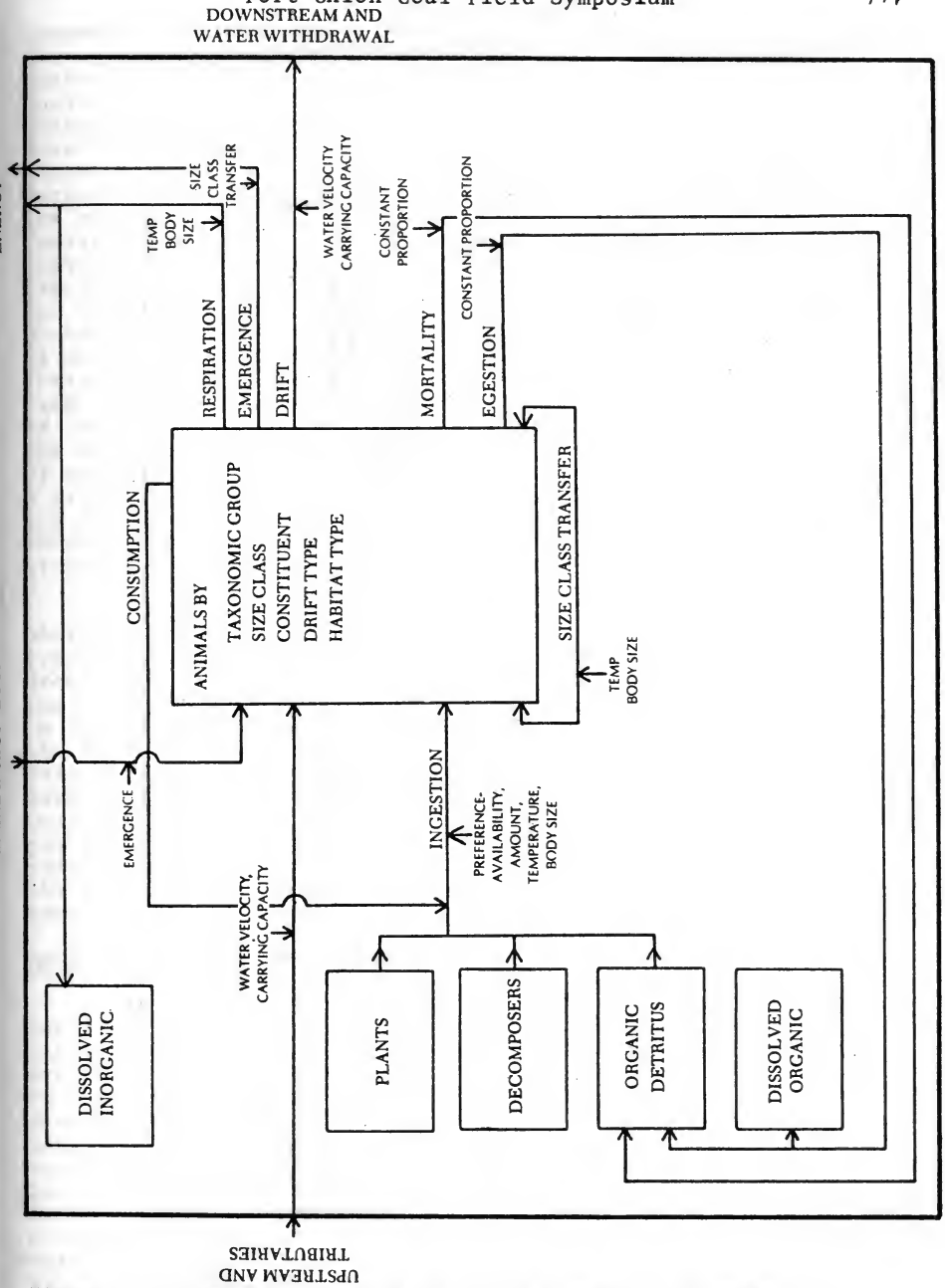

Figure 3. Processes and factors regulating fluxes for the animals in the general stream model.

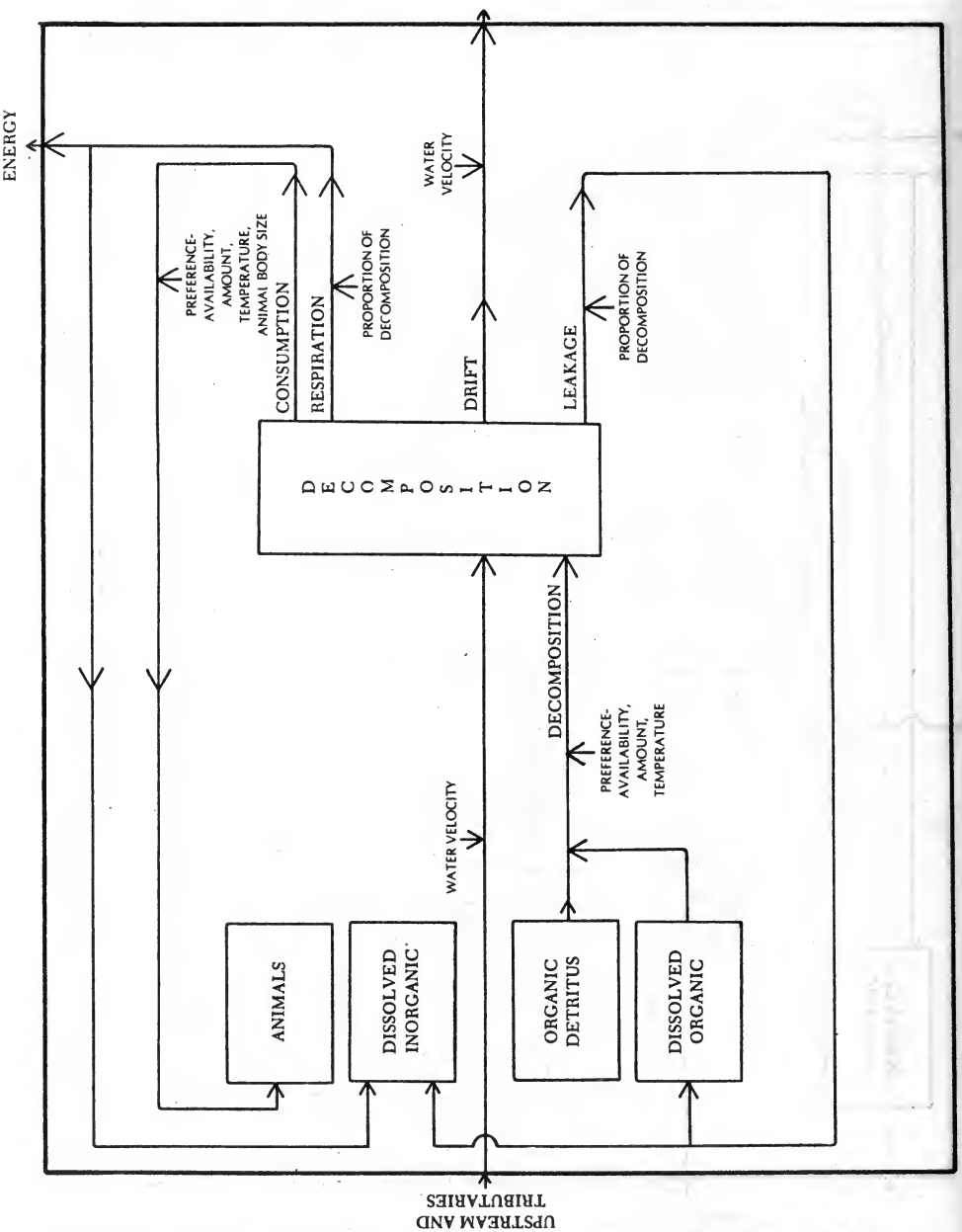

Figure 4. Processes and factors regulating fluxes for the decomposers in the general stream model.

temperature (an exogenous variable), the amount of space available for a plant group, and by the availability within the plant of nutrients needed to convert photosynthate into new cell materials. Photosynthesis will take place only to the extent that the requisite inorganic constituents are available in the surrounding water. The rate at which nutrients are taken up to "match" the photosynthesis is proportional to the difference between the internal concentration and that which would be in equilibrium with the existing external concentration; if the external supply is constantly renewed, then the internal concentration will be asymptotic to this equilibrium value. The demands by the various plant groups for all nutrients from the surroundings are summed, and compared with the amounts available. If any is inadequate, photosynthesis is scaled down by all plants in such proportion as allowed by the limiting nutrient. Plants dying in the ecosystem do so as a function of temperature and as a constant for each particular plant group. The dead material increments any of the benthic or suspended litter categories, as specified by the user at execution time. Those plants dying as a function of temperature do so only down to a propagule biomass, which is a proportion of the maximum amount of that plant occurring during the previous year. Plants also leak organic solutes to the surrounding water, at a rate which is constant for each plant group but may vary from group to group.

Those plants that are considered sessile in the ecosystem, whether they are attached algae or rooted angiosperms, may colonize an area at certain times or may be washed out of an area at other times. Colonization occurs between specified days of the year, but only if the water velocity is below a critical value. On these occasions a set fraction of the plants drifting into the ecosystem are allowed to colonize the area. When the water velocity is above a critical value, plants are "uprooted" and washed out of the system. If the plants are uprooted between "colonization" days as specified above, then a proportion of the plants leaving the system remain viable. The rest of the "uprooted" plant enters the suspended detritus and is washed out of the system. Viable plant parts may also leave the system at a constant proportion between specified dates.

Animal section

The animals within the system may ingest any plant, animal, detritus type or microorganism, whether it be suspended or benthic. The foods they actually ingest are controlled by a preference-availability factory for each of the possible foods, as well as by the amounts of each of those foods. The maximum amount of food ingested by an animal group is controlled by an input parameter which is a scaler multiplier of the weight of that group, with this amount being scaled down by a number of factors. These include the amount of weighted foods available to the animal group under consideration, the size of the animal group and water temperature. Assimilation is a constant proportion of ingestion, with growth equaling assimilation minus respiration, which itself is a function of temperature and the average size of an individual.

Maximum ingestion can only be reached with unlimited food

supplies by a cohort that is at its minimum weight and at a temperature for maximum growth. When the individuals of a cohort are at their maximum weight, ingestion balances respiration and egestion, which occurs at assimilation rates below unity. Part of the egested material may go into solution, with the remainder being added to specified litter categories. All ratios of chemical constituents or energy to carbon are kept constant within an animal group, with possible variations because of the diet being agested. Energy of respiration is considered lost to the ecosystem by way of the atmosphere, with other respired products entering the dissolved inorganic compartments, either benthos or water column, depending on the habitat of the organism in question.

For the transfer of animals of one size class or cohort of a species to the next larger size or older cohort, several alternatives are provided:

1. The rate of transfer may be a function of accumulated mean daily temperatures, in excess of a specified threshold, starting from when animals entered a particular cohort, with the transferred animals remaining within the ecosystem.

2. The rate of transfer may be an exponential function of temperature on a particular day.

3. The transfer is regulated the same as for number 1, except here the transferred animals leave the system as flying adults.

4. Transfer occurs on the last day of the year.

5. Transfer occurs as a function of the weight of an average individual above a certain specified weight.

6. No transfer occurs.

At the time of transfer, not all of the biomass may enter the more mature cohort. A fixed proportion may be transferred as exuviae to specified detrital categories.

A number of alternatives are also provided for the type of transfer from cohorts to the eggs of the same species:

1. Transfer to eggs occurs during specified times of the year if the temperature lies within a certain range.

2. A constant reproduction occurs between upper and lower threshold temperatures.

3. If the species is the variety that has aerial adults, and if adults hatched on that day, then a constant number of eggs are laid for that species.

4. No eggs are laid by the group.

Animals also have non-predatory mortality, which is fixed for each group, with the dead entering any of the detrital categories specified at execution.

Many invertebrates drift into and out of the ecosystem; this is divided into two categories in the model, catastrophic and behavioral drift. Catastrophic drift occurs as a function of water velocity, with animals drifting into the system being allowed to colonize during periods of low flow, or animals in the system being swept away during high water periods. Behavioral drift is considered as a function of carrying capacity monitored as the difference between the amount of food an animal "wants" to ingest and the amount it is allowed to ingest as a function of food quantities. Thus, the lower the food supplies, the greater fraction of animals leaving the stream section. Immigration is calculated as the complement of emigration.

Decomposer section

The microorganisms of the system act to decompose any of the benthic or suspended detrital categories and the dissolved organic constituents. The use of these substrates by different categories of microbes is expressed, as in the case of animals, by a preference table. The total substrate utilization is calculated by a Michaelis-Menton function using temperature and the weighted total of the substrates available. The amount of substrate mineralized is a constant fraction of the substrate used, with the elements entering the dissolved inorganic compartments of the system. Another constant fraction is added to the protoplasm, with the remainder being lysed or leaked and added to the dissolved organic compartments. The microorganisms that are attached to substrates in the water column or that are in the benthos may also be scoured or deposited as a function of water velocity.

MODEL USES

The model has the potential of being a theoretical as well as a managerial tool. Its theoretical value is its use in studying the dynamics of a total ecosystem through time. This is possible because the model tracks through time, either in tabular or graphical form, the mass of all components of the system, all exchanges of constituents between the ecosystem and the surrounding biosphere, productivity, either in daily increments or for an entire simulation period, and all the fluxes occurring between the state variable within the system. In addition to this output which is by taxonomic group, the model internally computes the fraction of the diets of all animal groups, thus allowing additional information such as community energetics or productivity respiration ratios, to be gained at the trophic level, where much ecological theory is now based. Many of the driving variables and physical characteristics of the stream may also be included as output.

The model may also be used as a managerial tool for evaluating perturbation and planning future research. In evaluating perturbations a stream ecosystem is simulated using the model and the best information available for a particular stream section, with output variables from the computer being saved on an external tape. Changes are then made to the data deck simulating a perturbation and again the program is executed with the output variables being saved. This step may be performed as often as necessary until all perturbations are simulated. Another

program then brings together all external tapes for each variable of interest, simultaneously graphing the standard and all perturbed simulations. Figure 5 is an example of such output. The abscissa is time in days, and the ordinate may be any variable mentioned in the introduction. The solid line represents the simulation using actual field measurements for exogenous input. For the perturbed simulations all of the data and parameters used were the same except for temperature which was reduced by 5°C in the case of the dashed line and increased by 5°C as represented by the dotted line.

Because the model is still in the development stage, Figure 5 can not be used for predicting the changes of mayfly biomass as a result of temperature changes. It was used, along with 800 other graphs of a similar nature, for an exploratory sensitivity analysis. Quoting Noy-Meir and Goodall (1):

> "The purpose (of exploratory sensitivity analysis is to test the response of a model over a wide range of conditions, in order to get some feeling for its general behavior and to see whether this behavior is at least qualitative over this range . . . Even if the parameter values used are not accurate values for any particular species or site, the trends in the model responses should indicate at least any pecularities in the behavior of the model, which might lead to revision of its structure."

Besides changes of temperature, simulated perturbations of discharge, solar radiation and concentration changes of inflowing detritus and inorganic constituents were made. The above analysis was conducted using data sets describing two different geographical areas. One data set simulated Deep Creek, a cold desert stream in Idaho sampled as part of the International Biological Program, Desert Biome, aquatic studies. The second set represented a generalized mountain stream, collected as part of a grant to study the effects of reducing discharge.

Another type of perturbation may be studied by the simulation (Figure 6). In this case it is assumed that a chemical treatment is performed on the stream, with the first order reactions being previously known and inputed in a parameter set. The addition in this case was on June 1 and initially affected the system by killing three-fourths of the plant biomass, with time to recovery being studied.

FUTURE PLANS

Plans for improving the model are progressing along five main fronts. First, exploratory sensitivity analysis has led to recommendations concerning the structure of the model as well as the parameter sets used for simulations. These are presently being examined. Second, an extensive literature search is being performed to point out areas of concern in real world situations which are presently notincorporated into the model. Problems such as microhabitat selection, anchor ice formation and its effects on the biota, behavioral relationships between and among species are examples of areas which must be considered. Third, comparison of model output with field measurements is planned. On Deep Creek, an area extensively studied

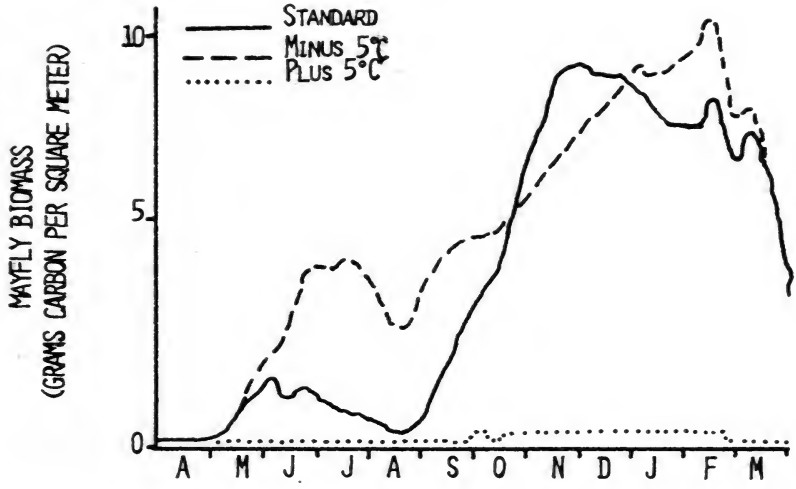

Figure 5. Predicted response of mayfly biomass to changes in temperature.

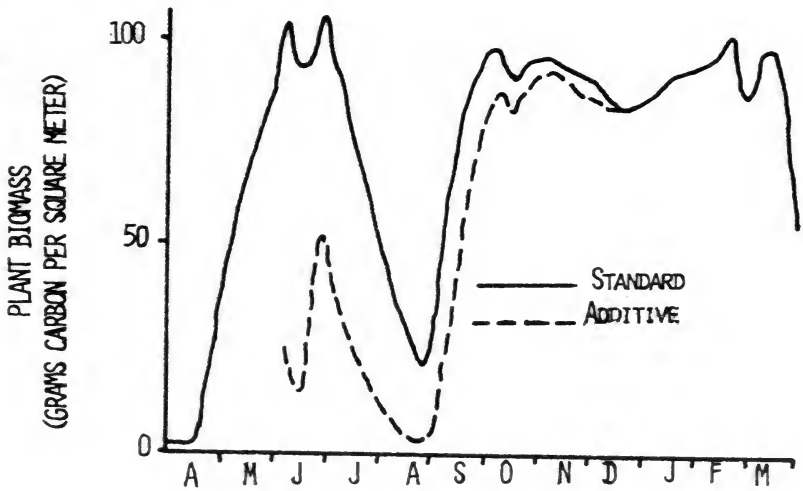

Figure 6. Predicted response of plant biomass to a chemical treatment which initially kills three-fourths of the plants.

by members of the aquatic section of the Desert Biome, a major perturbation is planned for the spring and summer of 1975. The perturbation will involve three sections of stream, one to be left in its present condition, another to have approximately 70 percent of the incoming radiation removed, and another to be completely shaded. Field measurements of key variables will be compared with model output. Fourth, the members from the Utah Cooperative Fishery Unit have proposed a seven year study which will result in further model development and validation. This study will consider the effects of streamflow diversions upon the physical and biological components in high mountain streams with a further aim of producing a methodology for impact evaluation which more efficiently, accurately and simply predicts changes. Lastly, the coordinating committee for model development is searching for new uses for the model. We offer the model at its present level of development in exchange for expertise in different fields of aquatic systems to be used to further aid in development of the model.

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WATER REQUIREMENTS AND WASTEWATER POTENTIAL OF COAL-ENERGY FACILITIES

J. L. Thomas*

The importance of water as a limiting factor in the semi-arid Northern Great Plains depends upon the specific location of an energy conversion facility. Water requirements for coal-fired power plants and coal-gasification plants are not inflexible, but can be modified, within limits, to match available water supplies. Likewise, the volume and characteristics of wastewater from such facilities can be varied.

POWER PLANTS

A modern coal-fired electric generating plant burns coal in a boiler to produce high temperature, high pressure steam, which passes through a turbine where the thermal energy of the steam is converted to rotating mechanical energy. The turbine transfers energy to the generator, which produces the electrical energy. After turning the turbine, the steam enters the condenser, where energy is transferred to the cooling fluid, and the steam reverts to the liquid state. This last step produces very low pressure on the outlet side of the turbine, which is necessary for efficient operation of the plant. The lower the outlet pressure, the higher the efficiency; the more heat absorbed by the cooling fluid, the lower the pressure will be; and the lower the temperature of the cooling fluid, the more heat will be absorbed.

Due to the inefficiencies in the conversion processes, energy is lost at each step in the process. The laws of thermodynamics limit the overall efficiency of a coal-fired plant to approximately 40%. Hence, each kilowatt hour (KWH) of electricity (one KWH is equivalent to 3413 Btu's) requires a "heat rate" of 3413 ÷ .40, or 8533 Btu's. Some energy, approximately 10%, enters the atmosphere through the smokestacks. Another 5% is lost within the plant. So the heat that must be rejected to the cooling system is equal to .85 x 8533 - 3413, or 3840 Btu/KWH, which represents 45% of the energy obtained from burning the coal. Thus, for each 100 units of energy produced in the plant, 40 leave as electricity, 10 go up the smokestack, 5 are lost within the plant, and 45 are rejected to the cooling sytem.

Two fluids are used to absorb the heat rejected in the condenser: water and air. At the present time only one plant in the United States utilizes air as the cooling medium, in so called dry cooling towers. All others require water. Although power plants also use water for other purposes, such as boiler feedwater to supply the steam, in ash handling and stack gas cleaning,and service water for drinking, cleaning, and sanitary purposes, more than 95% of the water requirement in a wet system is for cooling.

COOLING SYSTEMS

Wet Cooling

The cooling water requirements of a power plant are dependent

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upon the size of the plant, local climatic conditions, and type of cooling system used. Cooling systems may be grouped into two categories: once-through and closed cycle.

1. Once-through cooling. This is the most water intensive heat dissipation technology. Excess heat in the steam is transferred to water which has been withdrawn from a nearby river, lake, or ocean, and the heated water is returned to its source. In the past, once-through cooling was used extensively because of convenience and economy, low water consumption, and efficiency. Because it utilizes the lowest cooling temperatures naturally available, this method provides for the most efficient turbine operation. The large volume of heated effluent, approximately 100 cfs (cubic feet per second) for a 1000 mw (megawatt) plant, is considered a pollutant because it degrades water quality and can affect aquatic life adversely. Current Montana water quality regulations limit allowable temperature increases to 1-3°F, thus precluding the use of once-through cooling in Montana except under the most favorable conditions, i.e., small plants located near large volumes of water.

2. Closed-cycle cooling. In this method, also called evaporative cooling or wet cooling, excess heat is transferred to water as in once-through cooling. The heated water, instead of being returned to its original source, is exposed to the air so that much of the heat is utilized in the evaporation of part of the water. (The evaporation of one gallon of water requires approximately 8100 Btu's.) The remaining water, thus cooled during the evaporative process and by sensible heat transfer, is recycled to the condenser, and the process is repeated. Additional water must be supplied to replace the amount lost to evaporation and drift, and to maintain an acceptable level of dissolved solids. Normally, two to three percent of the water is lost in each cycle depending on the type of cooling device used. Typical devices are described briefly below:

a. Wet cooling towers are devices in which the warm cooling water flows over packing material. The water is cooled by evaporation and convection as air moves through the packing. Air movement can be induced by a fan (mechanical draft wet cooling tower) or by a chimney effect (natural draft wet cooling water). Natural draft hyperbolic towers, which rely on the density difference between warm moist air in the tower and cooler ambient air outside the tower to create the draft, function best at conditions of high humidity. Tower size and cost increase rapidly at low (35% or less) relative humidity. Therefore, mechanical draft towers are favored in the semi-arid northern plains.

b. Cooling ponds are simply artificial lakes which utilize the natural heat exchange processes of evaporation, convection, and radiation to dissipate the power plant's waste heat to the atmosphere. Where sufficient land is available at reasonable prices, cooling ponds are often the simplest, cheapest, and least water intensive cooling method. Land requirements are on the order of one to two acres per megawatt. Ponds have the added advantage of being able to provide storage for extended periods in event the original supply of water is interrupted.

c. Spray ponds use fixed or movable nozzles to produce spray droplets. Cooling results from evaporation and convection as the droplets move through the air. Spray ponds require only about 20% of the land area needed by a cooling pond, but water and energy requirements are significantly higher. Localized icing and fogging may also be a problem.

Dry Cooling Towers

Dry-type towers use air to absorb the excess heat produced in the generation of electricity. There are two types of dry cooling systems:

1. Direct. This system employs a direct air condenser to dissipate heat in the turbine exhaust steam, thus condensing the steam to water.

2. Indirect. In this method the turbine exhaust steam is condensed by cooling water which then is run through a series of exposed pipes - an air heat exchanger - where the heat is transferred to the air as in an automobile's radiator. No cooling water is lost through evaporation, and no blowdown or makeup water is required.

Because air is not as efficient as water in transferring heat, a much larger heat transfer area is required in dry cooling. Piping requirements are much more extensive, necessitating a higher initial investment. Operation and maintenance costs are also higher.

The disadvantages of dry cooling are partially offset, however, by certain advantages. No makeup water is required for cooling, heat is not rejected to natural water bodies, and vapor plumes and icing problems are eliminated. Some savings may also acrue because of increased siting flexibility, i.e., assurance of an adequate supply of water does not influence location of the plant.

Wet/Dry Cooling

Wet/dry cooling permits a compromise between the higher capital cost and lower water requirement of dry cooling towers. Furlong (5) describes the latest developments in wet/dry technology - a system consisting of a standard wet evaporative cooling tower in combination with a dry heat exchanger. Fogging and icing can be eliminated or better controlled, and water requirements can be reduced substantially by designing the wet/dry tower to operate as a dry system most of the time. The wet, evaporative, part could be reserved for summer peaking requirements when ambient air temperatures are high enough to reduce plant efficiency significantly. Although equipment for wet/dry towers costs 1 1/2-3 times as much as that for conventional wood evaporative cooling towers, innovative designers are reducing both equipment costs and operating costs (1, 5).

WATER REQUIREMENTS

Intake Water

Table 1 summarizes water requirements of the various cooling

systems for the Northern Great Plains region. Estimated consumption varies from approximately 20 ac ft/year/mw for spray ponds to 1 ac ft/yr/mw for dry towers. Use at a specific plant would depend upon makeup water quality, plant characteristics, local climate, and water conservation practices. Taking the variability of these factors into consideration, the Northern Great Plains Resource Program (7) estimated that a 1000 mw plant using Yellowstone River water with a wet cooling system would require 8200-14,000 acre feet per year. This is somewhat lower than the 15,000 value of Table 1. It should be noted that of the wet systems, once through has the lowest consumption rate, approximately 7ac ft/yr/mw.

Wastewater

Closed-cycle wet cooling systems are designed to alleviate thermal pollution associated with once-through cooling. However, use of these devices does not entirely eliminate environmental problems. Fogging, drift, and steam plumes are common problems. Of interest in this analysis is the quality of any waters discharged from the plant. In addition to cooling, water is used for several other important functions in a coal-fired power plant. Each of these functions can contribute its own characteristic waste. Sanitary wastes are not unique to a power plant so they will not be discussed. More important are the wastes from (1) the condenser cooling system, (2) boiler feedwater treatment operations, (3) plant system cleaning water, (4) exhaust gas treatment system, and (5) solid waste handling system.

Where once-through cooling is not possible, auxiliary offstream cooling devices such as cooling towers and ponds are required. Since these devices, with the exception of dry towers, rely primarily on evaporation for cooling, dissolved solids gradually become more concentrated and periodic blowdown or flushing is required to remove these salts from the cooling system. The increase in salt concentration can result in a potential water pollution problem.

Boiler feedwater treatment systems use alum, chlorine, sulfuric acid, sodium hydroxide, ferric chloride, ferrous sulfate, calcium carbonate, chromate and polymers. Other plant discharges including boiler blowdown and system cleaning water may contain phosphates, sulfates, and acids. Normally, these chemicals and impurities pose no particular environmental problems if proper treatment and disposal practices are employed.

Flue gas desulfurization systems basedon lime or limestone necessitate the disposal of large quantities of sludge. Ponding and landfilling currently provides the major means for disposal of these sludges. The sludge could be the source of significant surface and groundwater pollution, depending upon the characteristics of the waste and the disposal site. Potential water pollution problems are the following:

1. Soluble toxic species
2. Chemical oxygen demand
3. Excessive total dissolved solids

Table I. Water Requirements of Alternate Cooling Systems

Type	Acre ft/yr for 1000 mw Plant				
	Evaporation	Blowdown and Drift	In Plant Uses	Other Uses[a]	Net Consumption
Once-through	6110	0	800	718,200	6910
Mechanical draft evaporative tower	9560	4810	800	---	15170
Natural draft evaporative tower	8960	4510	800	---	14270
Cooling pond (2000 acres)	13070	5190	800	-2,000	17060
Spray pond	9380	10870	800	-20	21030
Dry tower (mechanical)			800	200	1000
Wet/Dry tower	Water requirements are intermediate between dry tower and wet tower, depending on proportion of cooling load carried by wet portion of wet/dry system.				3000-15000

All numbers are from May and Kube, (6), except for those for dry towers and wet/dry towers.

[a] Other uses include discharge water from once-through cooling, and net seepage from and precipitation on ponds.

4. Excessive levels of specific species, e.g., sulfate and chloride, and

5. Excessive suspended solids.

Bottom ash is normally transported by water to settling ponds. The water can evaporate, seep into the groundwater, or be discharged into a stream. The decantate has a high pH and high concentration of dissolved solids (5000 mg/l). In addition, it is expected that trace quantities of arsenic, barium, copper, iron, mercury, lead, and other elements will be present in solution or in suspension in the decanted water.

It is anticipated that sludge generated from wet scrubbing processes and the bottom ash will be stored in ponds or used in landfill. For coal of 1% sulfur content and 10% ash (typical Montana coal), the volumes of sludge and ash will be approximately 85 and 215 tons of dry solids per megawatt per year, respectively (3). With average bulk densities of 42 pcf (pounds per cubic foot) for scrubber sludge and 85 pcf for ash, and 1000 mw plant would produce more than 200 acre feet of dry solids per year. Ash is relatively easy to dewater but sludge is not. Therefore, the solids probably would require a volume of 400-500 acre feet per year for storage.

Waters used to transport this material, as well as other wastewater from a power plant, obviously have the potential to degrade receiving waters and disrupt aquatic life. Under Montana regulations, discharges of sludges and water from sludges to waters of the state generally would not be allowed. Discharges would be permitted if the effluent either equalled or exceeded natural water quality: the receiving water body. It is likely that the waste would be stored in a sealed pond to prevent discharges or seepage. Barring failure of the storage pond, there should be little or no direct pollution resulting from aqueous discharges from a wet-cooled power plant.

The primary effect will be dewatering of the source stream because of the water consumed through evaporation, drift, and other losses. The effects of dewatering are difficult to predict. Dewatering can increase water temperature, decrease a stream's ability to transport and assimilate wastes, decrease the sediment carrying capacity, and lower the water level. All of these effects are potentially detrimental to other beneficial uses and instream values.

DISCUSSION

Selection of a cooling system for a given power plant depends on the following factors:

1. Water Supply: availability and quality

2. Climatic characteristics

3. Effluent standards

4. Cost and availability of land

5. Regulatory control: state, federal, and local.

An effective system will accomplish the required cooling, subject to physical and statuatory constraints, at the least total cost to the consumer. Table 11 compares the costs associated with easy method. Once through cooling requires the least capital investment as well as the lowest annual operation and maintenance costs (with the possible exception of some cooling ponds). Once through cooling, however, probably would not be permitted in Montana under current regulations. Mechanical draft evaporation towers or cooling ponds appear to be the next best alternative.

Dry cooling would avoid many environmental problems associated with closed-cycle wet cooling methods. In water short areas, dry towers appear to be technologically feasible. Townsend and Van Lanen (11) report that England has used dry cooling towers for a 120 mw plant since 1961; Germany operates a 150 mw dry-cooled plant; and Hungary cools a 600 mw station by dry towers. Black Hills Power and Light Company, which currently operates a 20 mw plant cooled by a dry-tower by Wyodat, Wyoming, is planning a 330 mw dry tower plant at the same site. The NGPRP (7) concludes that dry cooled plants are unrealistic at the present because of "reduced plant efficiences, higher heat rates, additional power requirements, additional fuel requirements, lower plant reliability, and higher capital costs."

Table II

Capital and Operating Costs for Alternate Cooling Systems

Type	Capital Cost $/KW	Annual Operation and Maintenance Costs mills/KWH
Once-through	9.90[a]	.05[b]
Mechanical draft evaporative tower	12.70[a]	.20-.25[c]
Natural draft evaporative tower	17.90[a]	.13-.16[c]
Cooling pond	13.50[a]	.01-.09[c]
Spray pond	10-17[c]	.10-.12[c]
Dry tower (Mechanical)	18.80[a]	.20-.40[c]
Wet/Dry tower	12-18[c]	.14-.16[c]

[a]From FEA, (4); [b] From May and Kube, (6); [c] From Boies, Levin, & Baratz (1)

Townsend and Van Lenen (11), on the other hand, argue that "dry cooling towers are a viable alternative to wet-type cooling towers in the arid plains of the Fort Union Region." Limited local water supplies or excessive water transmission costs would

make dry towers economically competitive with wet systems, particularly if the opportunity costs of water--the foregone opportunities for irrigation, municipal water supply, etc.--are considered.

Dry-type cooling towers or hybrid wet/dry systems should not be ignored by regulatory bodies. They may be preferable to wet methods in certain cases where the total cost, including opportunity cost, adverse environmental impacts of dewatering or reservoir construction, and the social cost of fogging and icing are severe. Technological advances--for example, the development of new turbines to operate at the higher back pressures characteristic of dry cooling--may overcome some of their apparent handicaps.

COAL GASIFICATION PLANTS

Although the basic chemistry of coal gasification is relatively simple--carbon from the coal is reacted with hydrogen from water at high temperatures to form methane or synthesis gas--there are a large number of conversion processes available. Chopey (2) listed 39 different systems for obtaining low Btu pipeline gas from coal. The Office of Coal Research's 1973 Annual Report (8) described 12 active research projects using various methods to convert coal to gas. The number is not surprising when one realizes that coal gasification was discovered more than 300 years ago and has been used commercially in Europe for several decades. Early processes, however, produced low Btu gas (approximately 150 Btu's per cubic foot) suitable only for local consumption. Gas for pipeline transmission, to replace or supplement natural gas, must have a Btu value of over 950 per cubic foot.

Consequently, technology for the production of high Btu gas from coal is still in the developmental stage. No commerical plants are currently operational in the United States. Estimates of water use and wastewater production from coal gasification plants must be based on proposed designs, not experience. Thus, values reported can be considered only as approximate at this time.

Water Use

Water and coal are the primary ingredients in any gasification scheme. Water is used in both processing and cooling. Water is also necessary for ash handling, sanitary purposes, and flushing of the cooling system. Water Requirements for a given plant depend upon moisture content of the coal, the gasification process employed, quality of makeup water, and type of cooling system.

Since energy conversion in the gasification process is more efficient than in coal-fired generating plants, 60% or more for the Lurgi gasification process versus 40% for a power plant, less heat is rejected in the conversion of coal to gas. Therefore, cooling water requirements are not as great. Coal-fired power plants with evaporative cooling typically require on the order of 150 gallons per million Btu output; a gasification plant may need less than 20 gallons per million Btu output.

In addition, the gasification plant will recover significant quantitles of saleable byproducts, some of which will also have appreciable energy content.

Probstein, et al. (9) published the most recent estimates of theoretical water requirement to supply a 250 x 10^6 SCF/day (standard cubic foot per day) gasification plant utilizing the Lurgi process. Their best estimate is approximately 4500 acre feet per year, of which about 25% is consumed in the gasification process. SERNCO (10) reports that a similar 270 x 10^6 SCF/day plant designed for northeastern Wyoming will require a minimum of 5240 ac ft per year if certain proposed processes are practical. Otherwise, 8700 ac ft per year would be consumed. Table III summarizes the water balance for the Wyoming plant. Note the figures do not include water for mining-related activities such as dust control or reclamation. Therefore, the figures of 6000 to 10,000 ac ft of water per year suggested by the NGPRP (7) are reasonable. The figures quoted are not necessarily minimum or optimal. As with power plants, the figures are influenced primarily by the amount of recycling within the plant and the nature of the cooling facilities. Water requirements are reduced as recycling increases and as more of the cooling is accomplished by dry methods. Further experience with prototype plants will doubtless refine these estimates.

Table III

Summary Overall Water Balance for Gasification Plant in Wyoming (250 x 10^6 SCF/Day)

Water Source	System 1,[a] base case gmp	Percent	System 2,[b] alternate case gmp	Percent
Inputs				
Raw water	3230	74.0	5398	82.6
Coal moisture	1061	24.3	1061	16.2
Miscellaneous	76	1.7	76	1.2
Total	4367	100.0	6535	100.0
Outputs				
Process consumption	1262	28.9	1262	19.3
Losses to atmosphere				
Process area	400	9.2	400	6.1
Water treating area	66	1.5	39	0.6
Utility area	2145	49.0	4106	62.8
Miscellaneous	191	4.4	191	2.9
Sub total	2802		4736	
Contained in solid wastes				
In ash	174	4.0	174	2.7
In sludges	129	3.0	363	5.6
Sub total	303		537	
Total	4367	100.0	6526	100.0

[a] mixed system with the effluent going partly to boiler feedwater and partly to the cooling system

[b] with effluent going to cooling water system only

Reference: SERNCO, (10)

Wastewater

Table IV identifies the quantity and nature of major sources of wastewater within a gasification plant. Ideally, all effluent water should be cleaned and reused within the boundaries of the plant. Trace elements in coal can be toxic if concentrated sufficiently. Thus, any aqueous discharges from the gasification process could be harmful. Ultimately, four things can happen to water entering the plant:

1. it is consumed in the gasification process

2. it is lost in cooling through evaporation and drift

3. it leaves the plant as blowdown water or process condensate

4. it leaves with the solid waste material, ashes and sludge.

Only items 3 and 4 have the potential to contibute directly to water pollution. The magnitude of the blowdown stream depends upon raw water quality, degree of treatment, amount of recirculation, and other design-factors. Because blowdown water and process condensate contain substantial concentrations of inorganic and organic compounds, plus variable amounts of toxic trace elements, which legally could not be discharged without extensive treatment, these will probably be disposed of in the ash ponds. If the ash pond is sealed to prevent seepage and constructed to prevent outflow, no ground or surface water pollution will result. Ultimately, the water will evaporate. Assuming zero aqueous discharges, the principal effect of a coal gasification plant on water quality, as with power plants, will be dewatering of the water supply.

Compared to coal-fired power plants, gasification plants are more efficient converters of energy. Design efficiencies exceed 60% for a gasification facility using the Lurgi process. For each unit of usable energy produced, the power plant will require approximately 25% more coal, consume 2-5 times as much water (assuming the power plant uses wet cooling), and produce up to 40% more solid waste.

SUMMARY AND CONCLUSIONS

Water requirements for coal-fired generating plants in Montana are reviewed for various cooling methods: once-through and closed-cycle wet cooling, dry cooling, and wet/dry cooling. All methods are technically feasible, although operational experience with dry and wet/dry cooling is sparse. Economics and government regulations are controlling factors in the selection of a particular method. An increasingly important factor is the opportunity cost of water consumed in the process. Generally, the cost of producing electricity from coal increases as the quantity of water consumed in the cooling process decreases. Water requirements range from 14,000 to 21,000 acre feet per year for a 1,000 mw plant using a closed wet cooling system. Dry methods theoretically could require only 1,000 acre feet per year. Dry and wet/dry systems, however, are unproven for large installations.

Table IV

Quantity and Nature of Major Wastewater Streams
from 270 x 10^6 SCF/Day Plant Proposed for Wyoming

Source	Design Quantity gpm	Nature
Major Phenosolvan Effluent	2947	Rich in NH_3, H_2S, and low-boiling organics
Minor Phenosolvan Effluent	1097	Rich in high-boiling organics, fatty acids, ammonia, coal dust and dissolved solids
Oily Sewer	180	Oily with suspended solids
Sanitary Waste	19	Like municipal sewage
Storm and Fire	67	Oily with suspended solids
Selected Blowdowns	327	Clean with moderate dissolved solids

Reference: SERNCO, (10)

Coal-gasification plants use water as a source of hydrogen for the product gas. In addition, the gasification process requires water for cooling, scrubbing, and cleaning. Total water requirements range from 5,000-10,000 acre feet per year for a 250 x 10^6 SCF/day facility. Gasification plants are more efficient energy converters than power plants, and they require less water per unit of energy produced.

Wastewater from power plants and gasification plants consist of cooling system blowdown which contains chemicals used to control scaling and solids concentrated during recycling and water used to transport ashes and solids removed by air pollution control devices. In addition, gasification plant wastewater from byproduct recovery will contain significant inorganic materials as well as small amounts of all organic compounds found in the coal. Normally, these wastes would be stored in large lagoons so that little or no outflow occurs. Any outflow, however, must conform to Montana water quality regulations preventing degradation of receiving waters.

The water used and the wastewater discharged by coal-energy facilities are not rigid quantities, but depend upon many design factors, including local climatic characteristics, the availability, cost, and quality of raw water, and discharge limitations on wastewater.

ACKNOWLEDGEMENTS

The work upon which this publication is based was supported in part by funds provided by the Old West Regional Commission.

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COMPUTERIZED DATA FILE OF ROCKY MOUNTAIN AND NORTHERN PLAINS MOLLUSKS FOR ENDANGERED SPECIES SURVEYS AND ENVIRONMENTAL ANALYSES

A PRELIMINARY REPORT

David Bickel*

INTRODUCTION

The Endangered Species Act of 1973 (P.L. 93-205) supplanted the Endangered Species Act of 1969 and instituted important changes in the management of threatened biota. The 1973 law clearly includes all species of animals and plants and in so doing makes direct reference to mollusks, crustaceans, arthropods and other invertebrates. Also the term "species" is defined to include subspecies or any other recognizable segment of a species that is represented by a viable natural population. The act establishes two categories of endangerment. An endangered species is formally defined as one in danger of extinction throughout all or a significant portion of its range. A threatened species is one likely to become endangered over all or a portion of its range in the foreseeable future. (1)

Over the past two years the Office of Endangered Species of the U.S. Fish and Wildlife Service has accelerated its efforts to gather more information on invertebrate species. Land and freshwater invertebrates, with the possible exception of river mussels, are outside the scope of traditional wildlife management, and most have little or no apparent economic importance in commerce or sport. There are relatively few systematists specializing with any one group of invertebrates and fewer still are in positions of service as resource people for wildlife management agencies. The total number of invertebrate and plant species is far greater than those of vertebrates, and the voluminous literature is so scattered that the non-specialist faces a difficult task when attempting to interpret the systematic and biological status of species.

The Office of Endangered Species reviewed data on mollusks gathered primarily from personal communication with malacologists and concluded that about one-tenth of both clam and snail species in the United States appear to be threatened. (1) This is similar to the percentage of vertebrate species recognized as endangered or threatened. It should be noted that most invertebrate observations so far have come from the eastern U. S. and Pacific Coast.

About 80 percent of all animals known to be threatened with extinction have geographically small ranges while the other 20 percent are widely distributed. It seems that a very small geographic range is a characteristic of most or all endangered and threatened molluscan species. In many cases this is a result of geographic speciation and local endemism but less often it

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results when relic populations survive amid Quaternary climatic-hydrologic changes. Among other groups, especially the freshwater mollusks of southeastern rivers, restricted species populations are the remnants left from declines in range and numbers that have taken place largely in the last 100 years.

The Office of Endangered Species has sought to increase the available data on the status of invertebrates in the U.S. by contracting specialists to carry out studies on various groups and geographic areas. Some project groups concerned with mollusks are concentrating on one or a few families in a region, such as river mussels (*Unionidae*) or river snails (*Pleuroceridae*), while others are surveying all mollusks within specified regions. The primary objective in all cases is to recognize species that are threatened, endangered, or very vulnerable to adverse environmental modification. Formal recognition of each taxon under the Endangered Species Act of 1973 requires data on its distribution, ecology, taxonomic status, and degree of jeopardy now or in the foreseeable future.

THE PRESENT STUDY

In July, 1974 a survey of the living mollusks of Utah, Colorado, Wyoming, Montana, North Dakota, and South Dakota was begun to meet the immediate objectives outlined above, and to achieve a long range objective of preparing a review of the mollusks of all or part of the study area. There are about 300 species and subspecies of living mollusks in the region under study with the exact number being uncertain since the validity of some forms is uncertain. Unnoticed misidentification by previous workers has probably added a few names to the regional list. Also, large portions of the region have not been thoroughly studied, for example, Cvancara (2) through limited statewide sampling of land snails found first records for three species in North Dakota. Best estimates of numbers of taxa by state are: Utah, 123; Colorado, 143; Wyoming, 153; Montana, 129; North Dakota, 168; and South Dakota, 150.

About 45 to 50 species, all gastropods, have known ranges so small that their status is under investigation as part of this project. Among the terrestrial snails many of the local endemics are members of the Oreohelicidae, while many of the aquatic forms are in the Lymnaeidae and Physidae. Most of these are located in mountainous areas, but this should not be inferred to mean the Northern Plains are devoid of local endemics that merit attention and management. The available data on the plains fauna does not permit such conclusions at this time.

Literature review and summary leading to a card file of known locality records, was a traditional and essential first step to surveying the fauna. However, it seemed that a computerized file could maximize use of the data in several ways. A computerized file could rapidly rearrange data into faunal lists by states, counties or major localities and also sort records by taxa. It would also permit retrieval of data on past collecting with the possibility of quickly knowing localities visited, when, and by whom. Rapid data handling can assist field work by making possible the identification of poorly studies areas and construction of species lists tailored to travel itineraries.

Having data stored in a computer system and available for statistical analysis of faunal similarity and recognition of zoogeographic units within the region was an obvious benefit.

Computer Science students at Minot State College, notably Loren Piper and Steve Peckham, designed simple programs to give the above capabilities with the modest limits imposed by available hardware. An IBM 1130 computer system and FORTRAN IV language is used with programs written largely from subroutines prepared by IBM. Operations are carried out by undergraduate students in an "open shop" computer center. Storage is presently on a single disk with storage capacity of 1200 species names and about 19,900 locality records. Storage is maximized by using one work (A3) format. Data cards contain the same literal data normally included in any faunal locality record such as taxon, locality, and information source. Records can be selectively retrieved by state, county, major locality, author and date of published records, or museum or field numbers. All records for any species can be retrieved, or species localities can be selectively listed for any of the above geographic units. Inherent in the system is the potential for easily expanding the numbers of data fields to include ecological information and supplementary references.

The design takes into account the need to update nomenclature and synonymy, and to add new records. Each species name is input from a single data card that can carry the names of up to three other species to be treated as junior synonyms. Thus, a nomenclatorial change involves punching one data card, and placing a species in synonymy can be done by entering the name on one data card.

PROPOSED OUTCOMES

The data file will support the Fish and Wildlife Service's efforts in behalf of the invertebrate fauna by providing a regional faunal review that is more flexible than traditional summaries. The known molluscan fauna of any area in the region can be rapidly listed and documented. Species associated with threatened and endangered taxa can be readily determined so as to provide data for habitat recovery or maintenance. Historical changes in populations can be documented where the data permits and field work by previous workers can be utilized fully to define population ranges. New localities and range extensions resulting from field studies can be evaluated and published more rapidly, and the usefulness of such data will be maximized since field operations can be guided by data file output. Obviously, such results are produced by biogeographers using traditional methods of datahandling, but we feel that only machine operations can provide such a variety of data combinations with the time and manpower available.

Although the results of this survey will be communicated in traditional published form, it is hoped that the computerized file can be maintained, expanded, and made available to individuals involved in gathering biotic data for environmental analysis in conjunction with impact statements. Basic data on specific areas can be made available to ecosystems studies. The descriptive faunal summaries presently included in many impact

statements can be improved by delivering data in summarized form along with relevant ecological and zoogeographical information, and clear indication of any threatened or endangered species.

The data file being assembled for this project does not represent a challenging application of computer technology since the requisite programming and operations are elementary. Likewise the organizational steps taken with the data are no different than those employed by modern biogeographers and systematists using "manual" techniques. Advantages are convenient storage and retrieval, extremely rapid rearrangement, and maximum usefulness and clarity for the non-specialist, all with a large amount of data (about 9,000+ locality records).

One approach to wildlife management in its new-found role is to develop an integrated and centralized computer data file system for the whole of the North American biota to include those vertebrates, invertebrates, and plants for which a great amount of data is available. Mammals, reptiles, amphibians, fish, birds, mollusks, some crustaceans and insects are obvious animal candidates for such a system. It seems a safe assumption that in many groups such data is in similar data systems to some degree, or at least organized for input. In all probability, even the least studied biotic groups could be effectively incorporated by enlisting the skills of the few active systematic and biogeographic specialists and utilizing their expertise with data scattered in museums, herberia, and the scientific literature. Computer hardware and software costs would be small and there are many systems now on line in government agencies and academic institutions capable of easily handling such a project. The greatest expense is the professional manpower and clerical support needed to gather and organize data for input. However, the same effort and expense will be inherent in any biological survey regardless of the data management system employed.

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MICROFLORA OF THE YELLOWSTONE RIVER: A PROGRESS REPORT

Loren L. Bahls*

INTRODUCTION

The Yellowstone River trophic structure is based on plant tissue photosynthesized from carbon dioxide and water by solar energy through the agent of chlorophyll. Streamside terrestrial plants contribute some of this organic matter in the form of leaves, twigs, and logs falling into the river. In the river, especially in backwaters, higher aquatic plants may be important; but algae--small, often microscopic aquatic plants--are probably responsible for the major share of primary production within the Yellowstone River ecosystem.

Algae are an important resource. They form the base of the aquatic food web that culminates in the production of fish and the satisfaction of fishermen. Oxygen, a byproduct of algal photosynthesis, allows the river to sustain animal life and to meet the demands imposed by decaying organic matter. Many algae are specific in their tolerance of environmental conditions and therefore serve as reliable indicators of water quality.

As important as the algal community is, we know virtually nothing of its productive potential, let alone its composition. As the last major free-flowing river in the continental United States, the Yellowstone offers a rare opportunity to study natural downstream succession. Imminent water resource development in the basin makes these baseline studies even more urgent.

PRIOR RESEARCH

Roeder (3) studied the diatom assemblage of the Gardner River, a tributary of the Yellowstone in Yellowstone National Park. Wright and Soltero (8) described the algal flora of Yellowtail Reservoir on the Bighorn River. Stadnyk (4) measured biomass standing crop and autotrophic index of the periphyton (attached) community at three stations between Gardiner and Billings. Westinghouse (6) indentified and counted plankton (suspended) algae at two stations near the mouth of Armells Creek. Williams (7) determined the percent occurrence of plankton algae at Sidney over a one year period. Bahls (1) (also reported in Montana Department of Natural Resources and Conservation (2)) identified suspended algae collected in three net samples taken near the mouth of the Bighorn River. Since autumn 1974, the U.S. Geological Survey (5) has been sampling monthly for phytoplankton and quarterly for periphyton and chlorophyll at a total of five stations on the Yellowstone, Tongue, Powder and Bighorn rivers.

OBJECTIVES

Objectives of the present study include: (a) determine the relative importance of periphyton and phytoplankton communities

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in the Yellowstone system and their interrelationships; (b) describe the seasonal and longitudinal succession of algal populations in the Yellowstone River; (c) determine the location and nature of the so-called cold/warm water "transition zone" as reflected by algal indicators; (d) determine the utilization of Yellowstone algae by filter-feeding fish, forage fish, larval fish and invertebrates; (e) determine the impact of present land and river uses on the periphyton community; and (f) estimate the impact of major water diversions and/or impoundments on primary production in the Yellowstone ecosystem.

METHODS

The Montana Department of Fish and Game has been collecting monthly periphyton and phytoplankton samples from 20 stations on the Yellowstone River since August 1974:

Corwin Springs	Custer
Mallard's Rest	Bighorn R. @ Mouth
Above Livingston	Hysham
Above Shields R. Mouth	Rosebud
Grey Bear	Below Miles City
Grey Cliff	Terry
Columbus	Glendive
Laurel	Intake
Above Billings (@ Duck Cr.)	Sidney
Huntley	Cartwright, N. D.

Sampling will continue for at least a year's duration except for months of ice cover or heavy runoff. An additional 10 stations, including major tributaries, have been sampled occasionally for periphyton by both the Fish and Game Department and the Department of Health and Environmental Sciences:

Yellowstone R. Backwater Near BN Discharge, Livingston
Shields R. Headwaters
Shields R. North of Wilsall
Shields R. North of Clyde Park @ Highway 89 Bridge
Shields R. @ Mouth
Yellowstone Below Shields R. Mouth
Boulder R. @ Mouth
Yellowstone R. East of Reedpoint @ I 90
Stillwater R. @ Mouth
Clark's Fork Yellowstone R. @ Mouth

Periphyton samples are collected by scraping rocks and other natural substrates with a pocket knife. Plankton samples are taken with a standard Wisconsin plankton net suspended in the current for approximately 5 minutes.

Algae from preserved samples are identified to genus and rank of abundance estimated according to volume. An aliquot is then acidified for diatom species identification. A permanent slide mount is made of the acid cleaned residue and then, beginning at the edge of the coverslip, successive fields are observed under 1000 magnifications until between 300 and 400 diatom cells are identified and tabulated. Abundance or the percentage contribution of each taxon is then computed. From these counts, diatom community diversity and other indexes of water quality

may be calculated.

PRELIMINARY OBSERVATIONS

To date a total of 45 periphyton samples have been analyzed including at least one from each of the 30 stations along the river, from Corwin Springs, Montana to Cartwright, North Dakota. It now appears that the cosmopolitan green alga *Cladophora* is far and away the single most important genus in the river, at least during autumn when these samples were taken. *Cladophora* is important functionally in purifying the water and also as an attachment site for aquatic invertebrates and other algae.

The most diverse and perhaps the most important group of Yellowstone algae are the diatoms. Dozens of genera and well over one hundred species have been identified so far. In addition to their water purifying activities, diatoms are grazed by aquatic invertebrates.

A distinct downstream succession in algal populations is apparent from these first analyses. Forms at the upstream stations are predominatly attached while motile forms become increasingly common downstream. Whether a true plankton develops in the Yellowstone, or whether suspended algae are derived primarily from the periphyton, is yet to be determined.

Further interpretations are not warranted at this early stage in the study.

RECOMMENDATIONS

Present monthly sampling should continue at least through a yearly cycle or until July 1975. It may be desirable to monitor selected stations thereafter on a less frequent basis.

Net primary production (i.e., biomass accrual) and autotrophic index measurements should be taken periodically at appropriate stations on the mainstem of the Yellowstone, particularly above and below major tributaries and known or suspected sources of pollution.

The stomach contents of representative fish and invertebrate species should be analyzed to determine what role Yellowstone algae may play in the food habits of these animals.

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LONGITUDINAL CHANGES IN THE MACROINVERTEBRATE FAUNA OF THE YELLOWSTONE RIVER

Robert L. Newell*

INTRODUCTION

The Yellowstone River is one of the last large unimpounded rivers in the United States. The river originates in Yellowstone Lake at 7733 feet elevation in Yellowstone National Park and flows about 50 miles before entering Montana at Gardner at 5413 feet elevation. The Yellowstone River flows across southern Montana for about 550 miles enters North Dakota and 9 miles later joins the Missouri River.

The objectives of this research are to inventory the aquatic macroinvertebrates of the Yellowstone River, gain some insight into dominant species, longitudinal succession and quality of the fauna through species diversity indices. This research is prepatory to future studies concerning flow requirements of the dominant macroinvertebrates.

Only two previous studies are known concerning the macroinvertebrate fauna of the river. Bergersen and McConnell (1) studied the fauna in Yellowstone National Park. Stadnyk (5) investigated the Plecoptera of the upper river.

I would like to thank Rod Berg, Dennis Schwehr and Larry Peterman for their assistance in this portion of the research.

METHODS AND MATERIALS

Twenty sampling stations were established along the entire length of the Yellowstone River in Montana (Table 1). Four Hester-Dendy type multiple plate artificial samplers (3) were placed and one kick sample of two minutes duration (4) was taken at each station. The artificial substrates operate to provide a "standard substratum" thus permitting data comparison between heterogeneous sampling stations. The supplemental kick samples were taken to ensure capture of the majority of the fauna and provide a semiquantitative sample.

All samples were washed through a no. 30 mesh brass sieve, preserved in 70% ethyl alcohol, labeled and returned to the laboratory. In the laboratory organisms were separated from detritus and sand, identified to genus and counted. Results obtained from the four artificial samplers were pooled. All results were placed on data sheets and sent to the State of Montana, Data Processing Bureau where the following species diversity indices were calculated (6,7,8):

$$\text{Shannon-Weaver diversity, } \bar{d} = -\sum_{i=1}^{s} (N_i/N) \log_2 (Ni/N)$$

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Equitability $(E_m) = \bar{d}/\log_2 S$

Redundancy $(R) = \frac{d_{max} - \bar{d}}{d_{max} - d_{min}}$

Maximum theoretical diversity

$$d_{max} = (1/N)\,[\log_2 N! - S \log_2 (N/S)!]$$

Minimum theoretical diversity

$$d_{min} = (1/N)\,[\log_2 N! - \log_2 \{N-(S-1)\}!]$$

where: S=number of species
N_i=number of individuals in the i^{th} species
N= total number of individuals

Samplers were installed at all sampling stations on November 12, 1974 and were removed every 4 weeks and replaced. Ice problems in January and February 1975 forced removal of the artificial substrates and only kick samples were taken from then on, Because only a few artificial substrate samples were taken for species diversity indices results obtained from kick samples were evaluated for species diversity indices and a comparison of the two methods will take place when a larger sample is available.

RESULTS

The Plecoptera of the Yellowstone River are represented by 13 genera (Table 2). Several of the genera are mono-specific in the Yellowstone River according to Gaufin et al. (2) for example: *Paraleuctra sara*, *Pteronarcys californica*, *Arcynopteryx parallela*, *Hesperoperla pacifica*, *Claassenia sabulosa* and *Pteronarcella badia*. The remaining genera are represented by at least two species. Very few adult Plecoptera have been caught in the lower river. One very interesting species is *Brachyptera fosketti*, previously unreported from Montana and now known to occur from the mouth of the Bighorn River downstream as far as Intake. In the upper river this species is replaced by *Brachyptera nigripennis*.

There is a gradual reduction in diversity downstream. Generally the Plecoptera comprise about 20% or less of the fauna at each station (Fig. 1), with individuals of *Isoperla*, *Alloperla* and *Isogenus* the most abundant. Numbers are somewhat misleading and if biomass was being considered the large Plecoptera would comprise a much larger percentage of the fauna.

The Trichoptera or caddisflies are represented by 17 genera (Table 3). Because the Trichoptera have not been investigated prior to this study very few species determinations are available and the generic list will probably increase with further investigation.

There is a steady decrease in diversity as one progresses downstream. The fauna is very sparce from station 12 downstream.

The Trichoptera are very abundant throughout the river

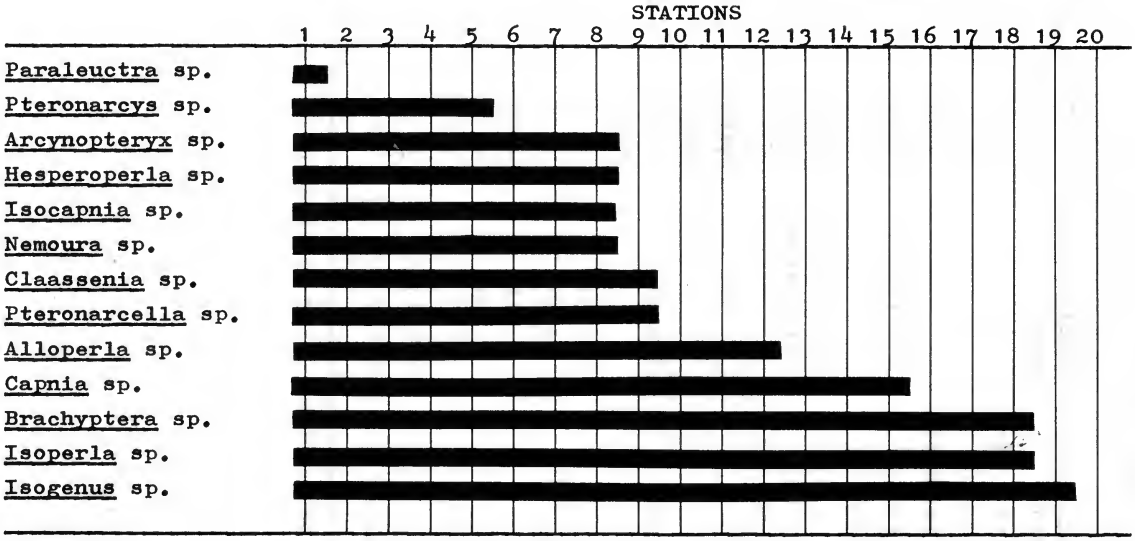
Table 1
Yellowstone River Sampling Stations

No.	Location	County	Elevation	River Mile **
1	Corwin Springs	Park	5110 ft.	549
2	Mallard Rest Access	"	4620	515
3	above Livingston	"	4490	501
4	above Shields River	"	4380	497
5	Grey Bear access	Sweetgrass	4100	468
6	below Greycliff	"	3880	444
7	Columbus	Stillwater	3566	411
8	Laurel	Yellowstone	3294	391
9	Duck Creek Bridge	"	3140	360
10	Huntley	"	3110	349
11	Custer	"	2720	300
12	Bighorn River	Treasure	2700	296
13	Myers	"	2640	279
14	Forsyth	Rosebud	2490	234
15	Miles City	Custer	2335	184
16	Terry	Prairie	2190	138
17	Glendive	Dawson	2045	93
18	Intake	"	1998	71
19	Sidney	Richland	1892	30
20	Cartwright,N.D.	McKenzie	1850	9

** Mouth of the Yellowstone River is river mile 0.0 .

Table 2

Plecoptera of the Yellowstone River



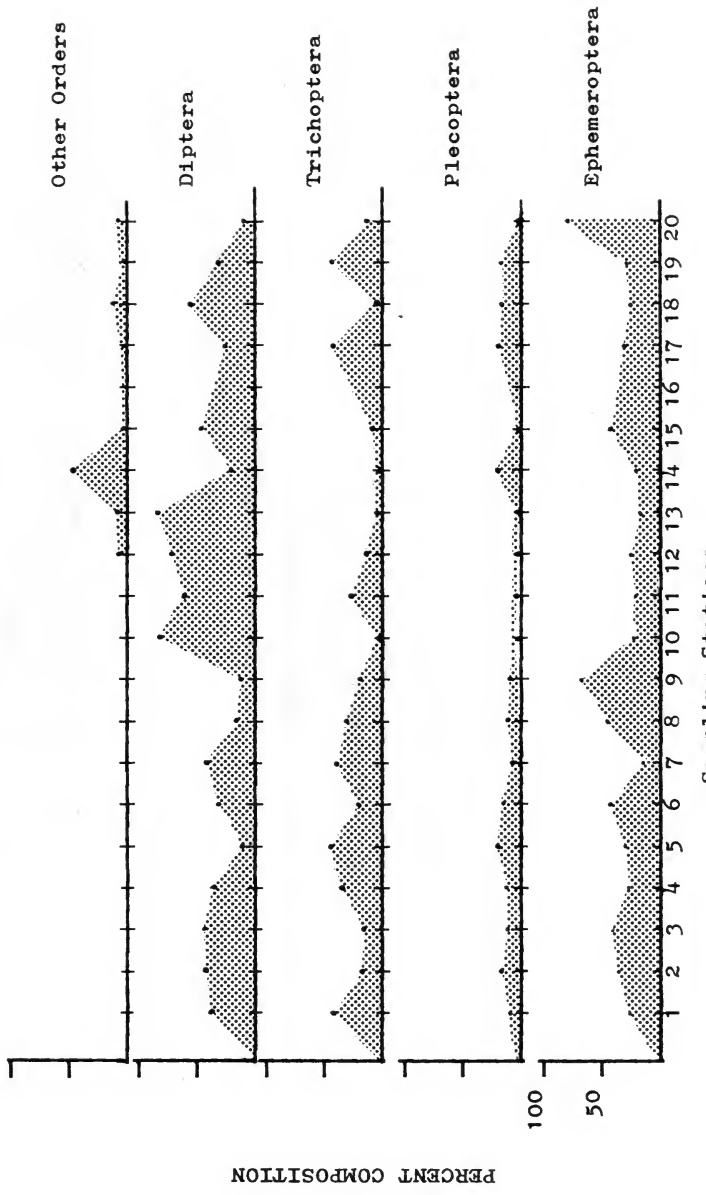


Figure 1
Percent Composition of Numbers of Organisms
in the Major Orders

Table 3

Trichoptera of the Yellowstone River

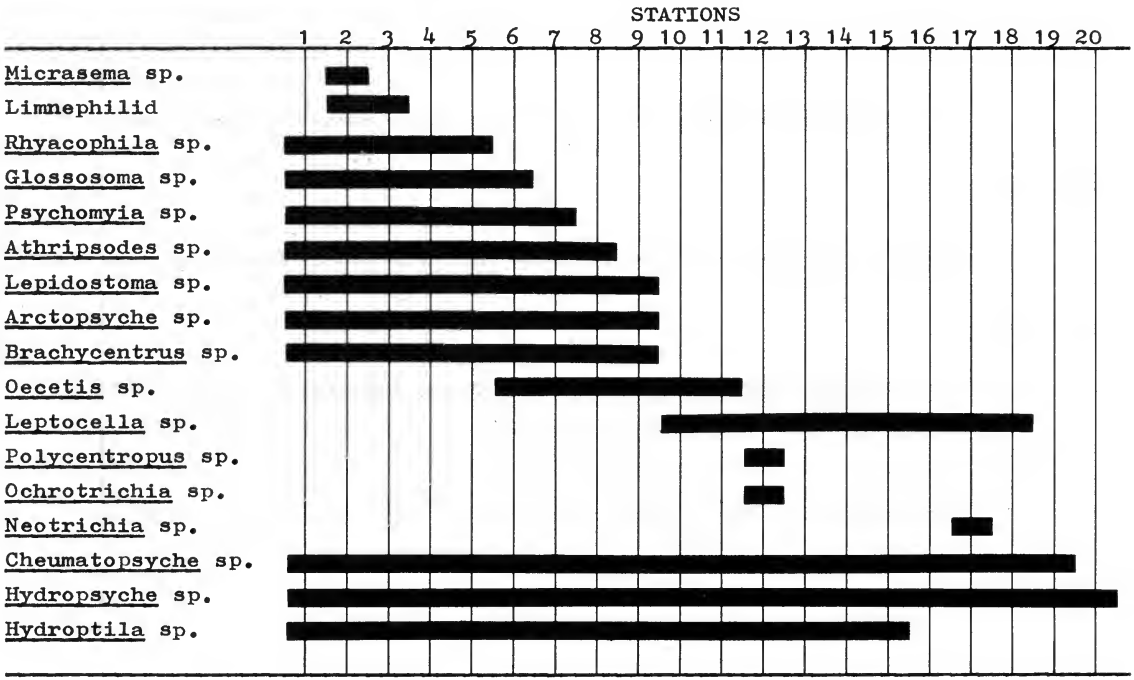


Table 4

Ephemeroptera of the Yellowstone River

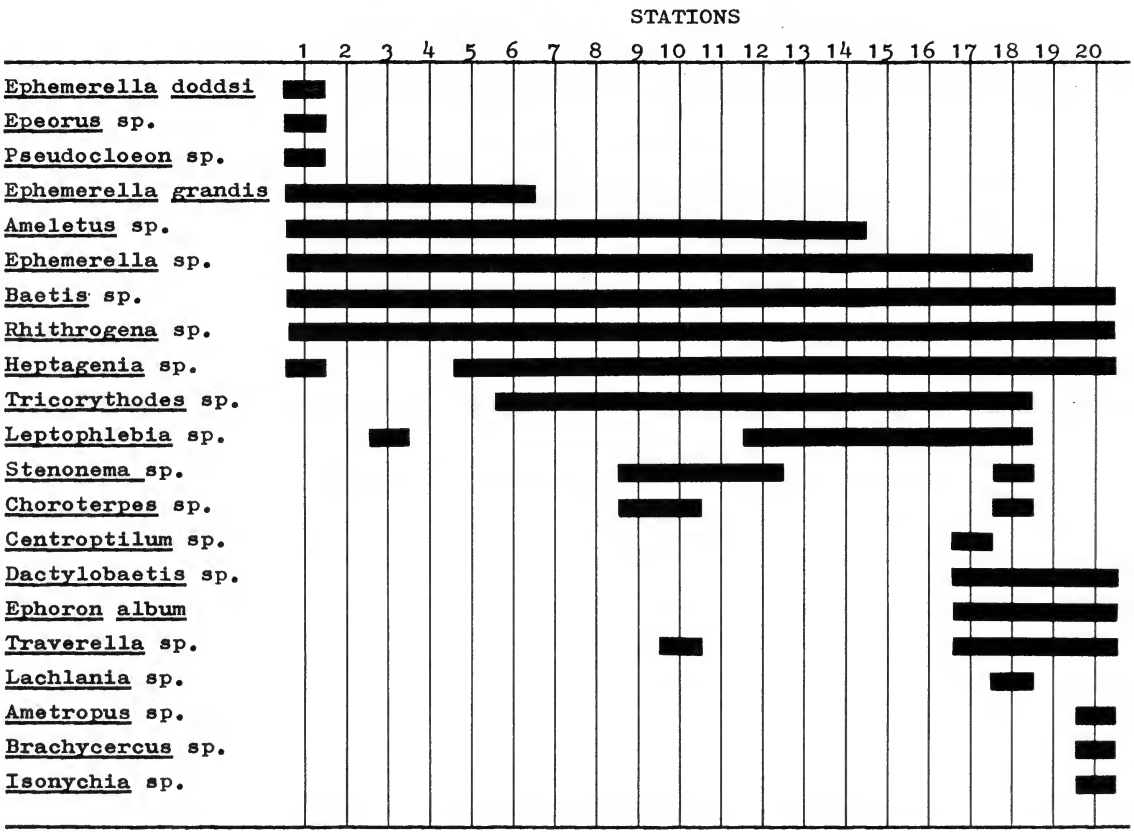


Table 5

Diptera of the Yellowstone River

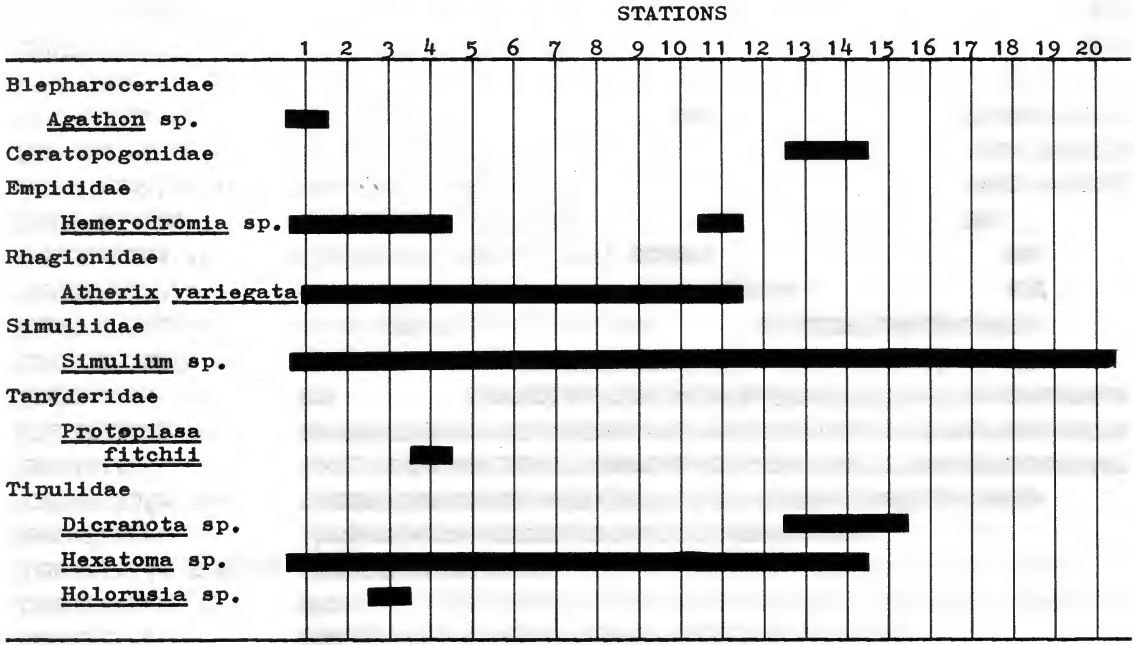
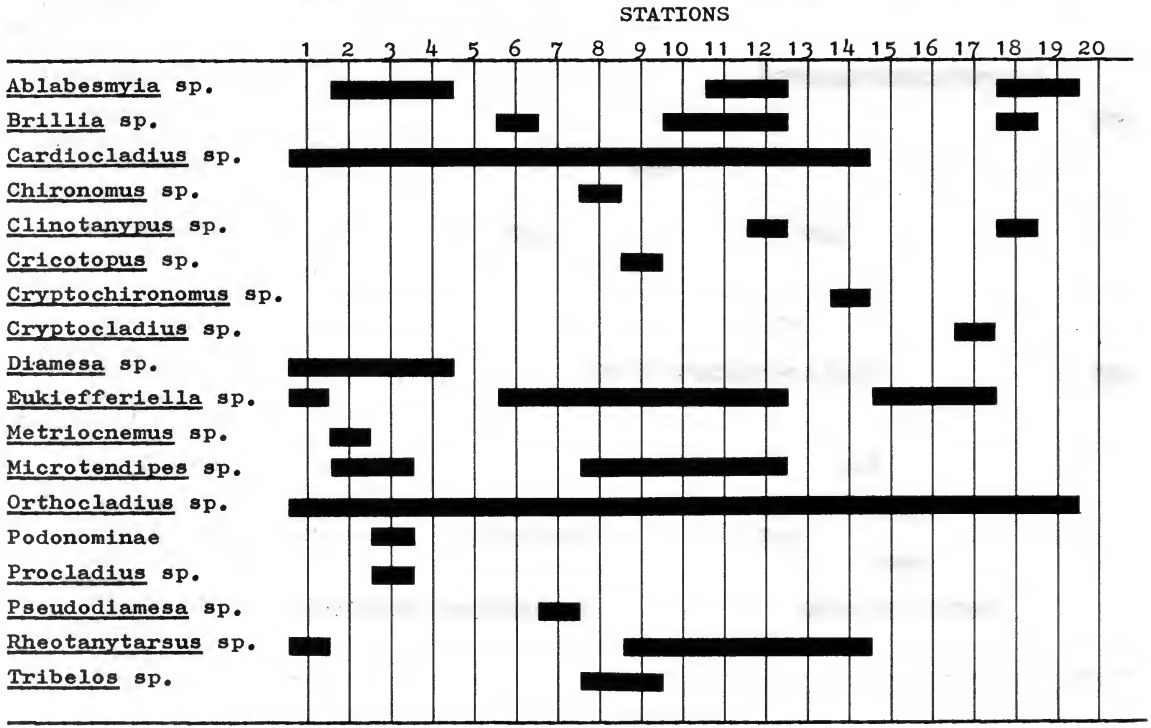


Table 6

Diptera (Chironomidae)[1] of the Yellowstone River



1- identifications are tentative at this time.

Table 7

Miscellaneous Orders of the Yellowstone River

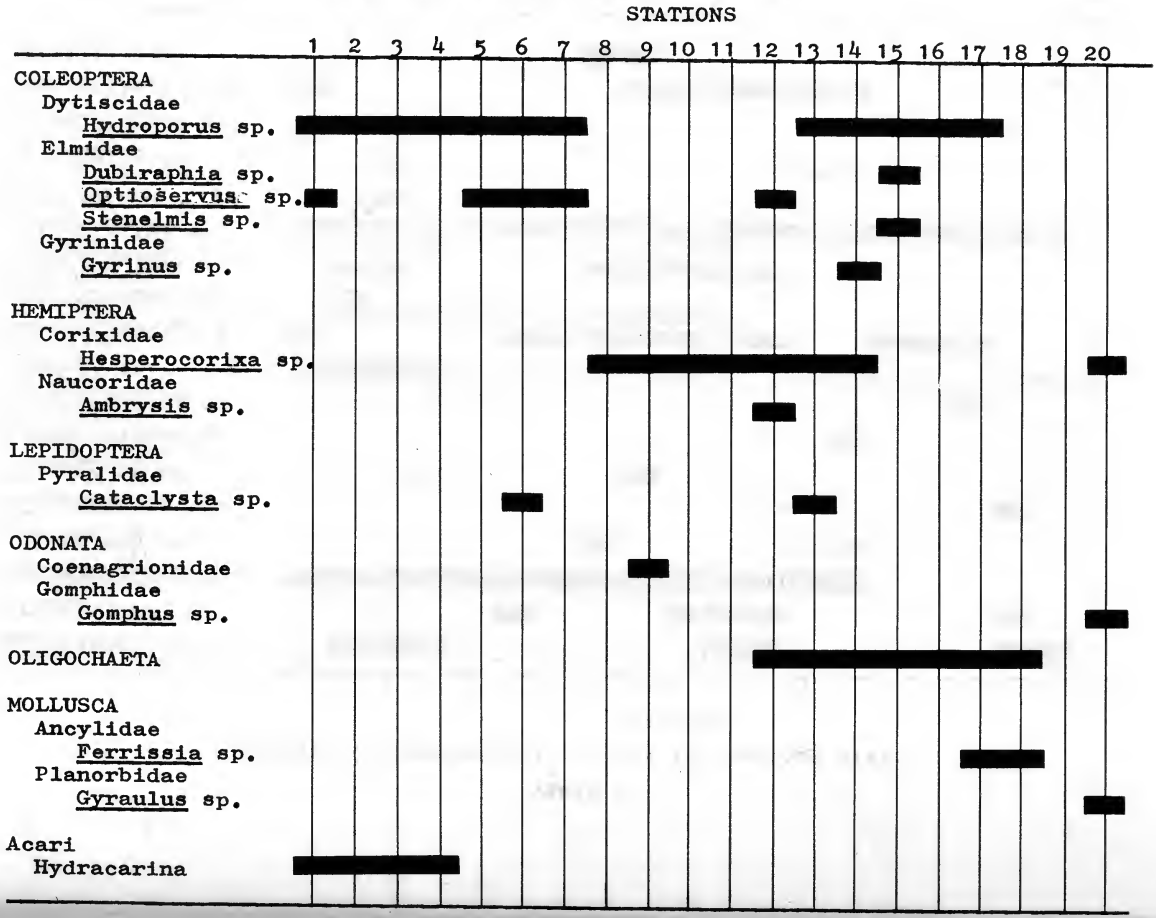
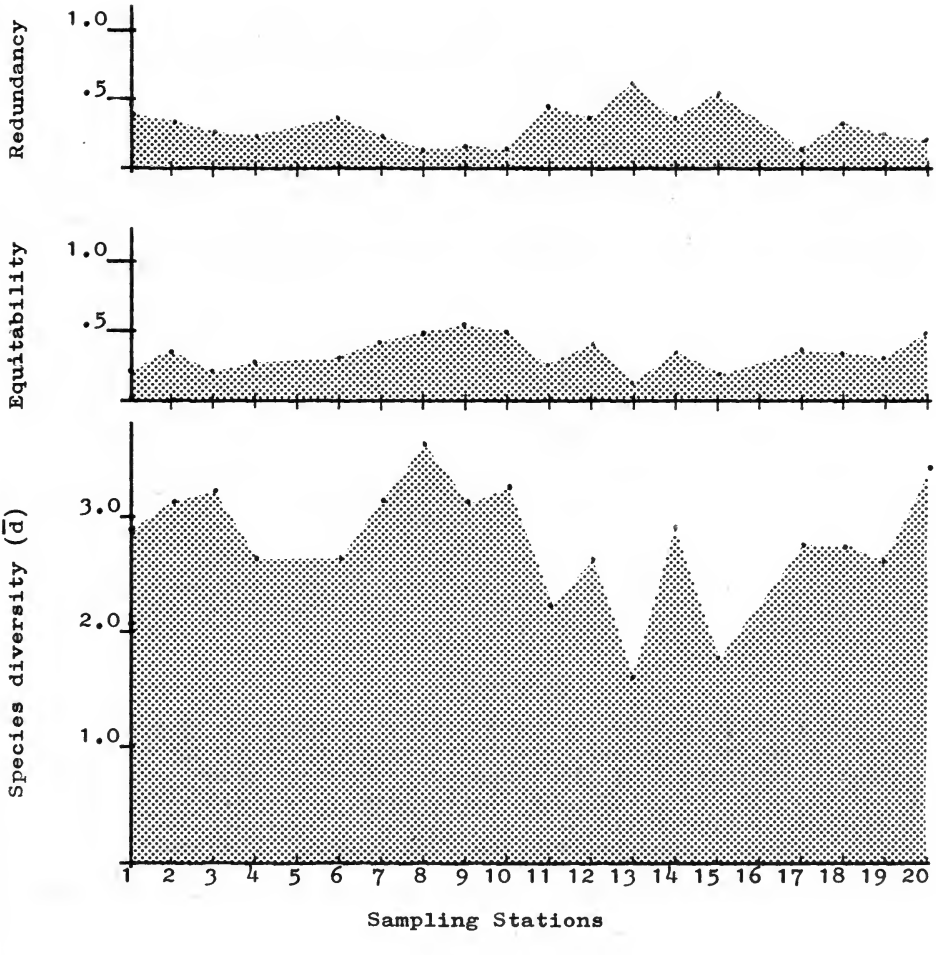


Figure 2
Longitudinal Changes in Species Diversity
in the Yellowstone River



(Fig. 1). Individuals of the genera *Cheumatopsyche* and *Hydropsyche* are the most commonly collected caddisflies.

The distribution of the Ephemeroptera or mayflies of the Yellowstone River is presented in Table 4. This group has not received prior study on the Yellowstone River. Presently 19 genera are now known from the river. There is about equal distribution of genera throughout the system. For example, there are 7 genera at sta. 1, 9 at sta. 10, and 9 at sta. 20. This is somewhat misleading because most genera found in the upper river are represented by several species e.g. *Baetis* spp., *Ephemerella* spp. Most genera found in the lower river are represented by a single species e.g. *Ephoron album*, *Traverella albertana* and *Lachlania powelli*.

The Ephemeroptera are an important component of the benthos throughout the river. At most stations mayflies comprise over 20% of the fauna with specimens of *Baetis*, *Ephemerella* and *Rhithrogena* the most abundant.

The distribution of the Diptera is presented in Tables 5 & 6. Presently the fauna is represented by 8 families and 26 genera. The Chironomidae are the most abundant, the most diverse and the most difficult to identify. Distribution of the fauna does not change greatly throughout the Yellowstone River. The Diptera comprise about one half the total number of organisms captured (Fig. 1).

Distribution of the miscellaneous orders is given in Table 7. The fauna of the 7 orders present is not very diverse and with the exception of the family Corixidae are not very abundant. Individuals of the Odonata and Mollusca will probably be found to be more diverse and abundant as backwater areas are sampled.

At stations 1-11 the miscellaneous orders comprise less than one per cent of the fauna and with the exception of station 14 they are not important in the downstream stations (Fig. 1).

The values of diversity, equitability and redundancy show the fauna of the Yellowstone River to be quite diverse and no stations appear to be under stress. With only 4 months of data further interpretation is impossible.

DISCUSSION

The macroinvertebrate fauna of the Yellowstone River is both diverse and abundant. Definite patterns exist in the longitudinal distribution of the fauna with the most dramatic changes evident in the Plecoptera and Trichoptera. The Plecoptera and miscellaneous orders are much less abundant than are individuals of the Diptera, Ephemeroptera and Trichoptera. The genera *Hydropsyche*, *Ephemerella*, *Baetis* and the family Chironomidae are the most abundant organisms present in the Yellowstone River.

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* * *

FALL-WINTER COMPOSITION OF THE BENTHIC MACROINVERTEBRATES OF THE TONGUE RIVER, MONTANA

James A. Gore*

INTRODUCTION

The benthic invertebrates, which represent virtually all trophic levels of the flow of energy through the aquatic ecosystem, and in particular the aquatic insects, represent the primary food source for the forage and game fishes. Any change in benthic invertebrate populations could result in changes in the overall biotic composition of the river.

The Tongue River in Montana is presently under study to determine the effect of possible streamflow alterations as a result of water needs by proposed energy-producing facilities in the area. It is assumed that the Tongue River represents a typical river system of the Fort Union coal field area. This paper is a study of the fall-winter composition of the benthic macroinvertebrates and is a partial inventory leading to a total seasonal index of the macroinvertebrate fauna of the Tongue River. This information will be used, in concurrent studies, to aid in establishing niche requirements with reference to factors most affected by reduced stream discharge.

Although the Tongue River has great oxbows typical of a meandering prairie river, the streamflow is not typically sluggish. Minimum daily flows during the fall and winter average 45 to 95 c.f.s. (cubic feet per second) (14). With the exception of the lower few miles of the river, where the substrate is sand and deposited sediment, the Tongue River has a substrate of medium angular cobble (128 - 256 mm.) and ranges to large cobble in some areas. Riffle areas are quite common. The river is unique in the presence of both cold water and warm water habitats. The climate of the area is typical of the Northern Great Plains, generally considered to be semi-arid. Vegetation along the river consists of cottonwood, boxelder, willow, wild rose, and several species of the grasses.

METHODOLOGY

Hynes (11) has stated that aquatic invertebrates, as a rule, have an inherent need for current, for the purposes of feeding and respiration. Riffle areas would provide the optimum feeding and dissolved oxygen situations. Riffle areas tend to be in the most shallow portions of the river and would be affected by reduced discharge first. It can be assumed that maintenance of riffle areas will result in suitable conditions in the rest of the river system. A comprehensive study of the riffle forms will provide information on those forms most affected by reduced stream discharge.

For the purposes of this study eight areas were designated as collection points and collections were taken through the fall

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and winter months, 1974 - 75. At each site two standard Hess samples were taken. The collections were then identified and counted in order to obtain an indication of relative abundance.

For all practical purposes, hyporheic organisms were not examined with the exception of those shallow burrowers which might have been disturbed in the sampling procedure. In addition, standing water and pool forms are not considered as this study is primarily concerned with riffle forms.

COLLECTION POINT DESCRIPTIONS
(see map next page)

Hosford I and II, Rosebud County, Montana, are one mile apart and about five miles below the Tongue River Reservoir dam, ten miles south of the main entrance of the Hosford Ranch. This area is considered to be in the cold water habitat section with the river bordered by pasture grasslands.

Birney I and II, Rosebud County, Montana are approximately two miles apart in the town of Birney, Montana. Birney I is located 100 meters below the entrance of Hanging Woman Creek. Birney II is located across from the Birney school below the entrance of a small sewage effluent. The river is bordered by cottonwoods, wild rose, and various grasses.

Ashland section, Rosebud County, Montana, is located beneath the bridge which crosses the Tongue River in the town of Ashland, Montana.

Viall section, Rosebud County, Montana, is located five miles above the Brandenberg bridge on the Viall Ranch.

S & H section, Custer County, Montana is located one mile below the road leading to the river from the south entrance of the S & H Ranch, about 100 meters below a small waterfall in the section.

T & Y Diversion, Custer County, Montana, is located at the Montana Fish and Game Department fishing access site, 12 miles south of Miles City, Montana, and 30 meters below the spillway.

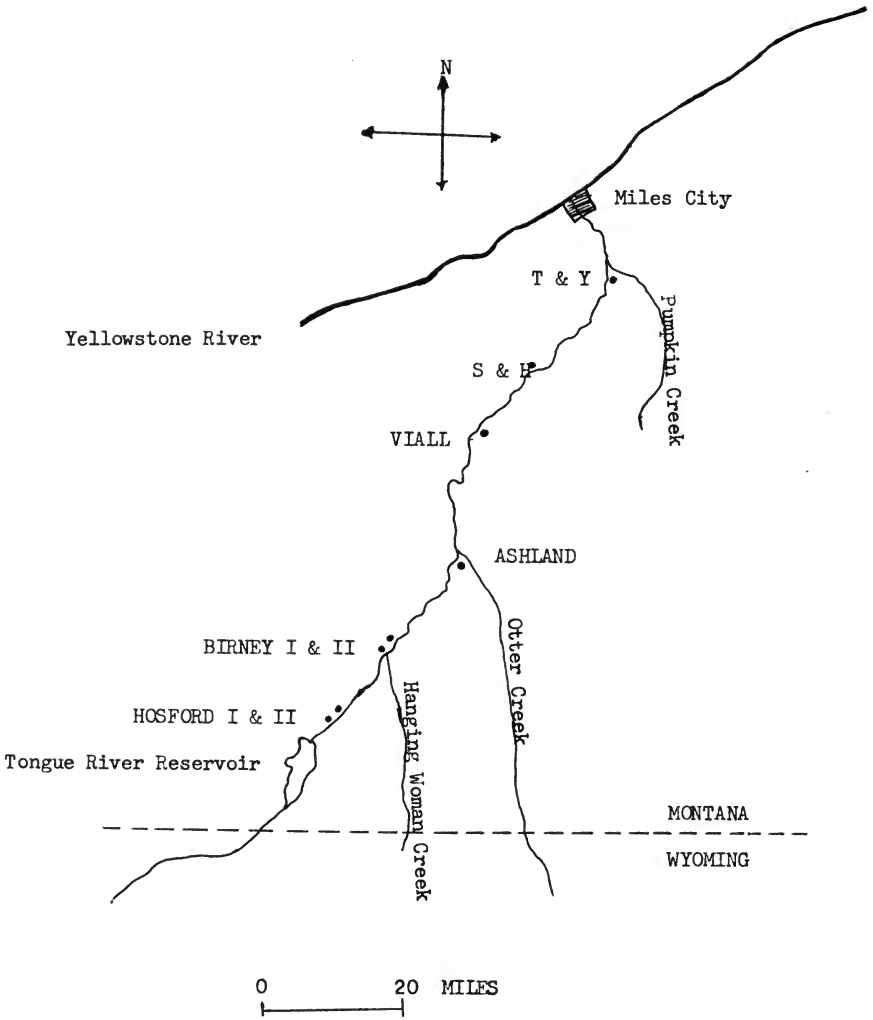
It should be noted that not all points were sampled in a given month due to inaccessibility to some areas during the winter monthes. However, each point was sampled once and most were sampled two or more times.

RESULTS

Collection area characteristics are listed in Table I.

The results of the collections are presented in tabular form (Table II) indicating total number of individuals and relative abundance, in percentage of total numbers, of the species collected.

Where possible, organisms have been identified to the species level. The collection consists of nymphal and larval forms for the most part and it will be necessary to collect adult stages


N
Miles City
T & Y
Yellowstone River
Pumpkin Creek
S & B
VIALL
ASHLAND
BIRNEY I & II
Otter Creek
HOSFORD I & II
Hanging Woman Creek
Tongue River Reservoir
MONTANA
WYOMING
0
20 MILES

during emergence to fully identify those forms designated only by generic names.

Four of the five species of *Hydropsyche* have been designated as *Hydropsyche sp. a*, *H. sp. b*, *H. sp. c*, and *H. sp. d*.

Hydropsyche sp. a has a head pattern similar to *H. recurvata* of the *bifida* group designated by Ross (18). However, variability in head patterns is so great that, as a single characteristic, identification can not be accurately made until adult forms are collected.

Hydropsyche sp. b. is similar to the head pattern of *H. simulans*. However, the light border at the posterior margin of the head as in *H. simulans*, does not exist in *H. sp. b*.

Hydropsyche sp. c is similar to *H. betteni* with the exception of lacking the light pattern at the posterior margin of the head.

Hydropsyche sp. d has no similarities to those larval forms presently described. The rust colored head has a pattern which encompasses the dashes near the eyes, as *H. simulans*, and the crossed pattern of *H. recurvata*.

Two dryopoid beetles have been designated as *Stenelmis sp. a* and *Stenelmis sp. b*. *S. sp. a* generally resembles *S. douglasensis* and *S. sp. b* generally resembles *Ordobrevia nubifera* as designated by Brown (2). However, the ranges of these two similar forms can not logically be extended to Montana. Brown states that several new species of *Stenelmis* are being reported from Idaho and Oregon. It is likely that *S. sp. a* and *S. sp. b* will be included in this group when fully described.

Where the designation "sp." occurs, it can be assumed that existing keys do not differentiate between larval forms and that more than one species may be included.

ANALYSIS AND DISCUSSION

From the presented data, a kite-diagram (Figure I) is presented showing relative abundance and longitudinal distribution. (Dashed lines indicate the presence of the organism in that section of the river, as determined by preliminary kick samples, but relative abundances have not been determined.)

It can be seen that the transition zone between cold water and warm water habitats (as delineated on the graph by Birney I) serves as the boundary for the southward distribution of many organisms. Only a few insect genera (*Baetis*, *Brachyptera*, *Hydropsyche*, *Simulium*, and *Metriocnemus*) extend the entire length of the river through both cold and warm water environments. Neel (16) states that if a reservoir is deep enough to become thermally stratified and has a hypolimnial drain, the discharge of cold water has a stabilizing effect on the thermal regime of the river below the dam, such that temperatures are considerably cooler in the summer and warmer in the winter. Hubbs (10) has found that the reduction of 24-hour temperature fluctuations causes a marked decrease in the number of invertebrate species.

TABLE I

SAMPLE POINT	TUBIDITY	SAMPLE DEPTH	SUBSTRATE	PERIPHYTON
HOSFORD I HOSGORD II	LIGHT	30 - 45 cm.	MEDIUM TO LARGE COBBLE	Cladophora, Spirogyra, dense mats
BIRNEY I BIRNEY II	LIGHT TO MODERATE	30 - 45 cm.	MEDIUM TO LARGE COBBLE	Cladophora, Spirogyra, sparse mats
ASHLAND	LIGHT	30 cm.	MEDIUM TO SMALL COBBLE	Nostoc, sparse Cladophora
VIALL	MODERATE	30 - 45 cm.	MEDIUM COBBLE	Nostoc, sparse Cladophora
S & H	MODERATE TO HEAVY	30 - 45 cm.	BEDROCK WITH MEDIUM COBBLE	Nostoc, moderate cover
T & Y	HEAVY	30 - 45 cm.	MEDIUM COBBLE AND SAND	Nostoc, moderate cover

TABLE II

	HOSFORD I	HOSFORD II	BIRNEY I	BIRNEY II	ASHLAND	VIAL	S & H	T & Y
(total numbers)	(98)	(119)	(247)	(773)	(76)	(83)	(51)	(135)
EPHEMEROPTERA								
Choroterpes sp.			1.6	.4		2.4		1.5
Paraleptophlebia debilis			.8	.8	1.3			
Leptophlebia sp.			.4					
Baetis sp.		2.5	.4	3.2			2.0	3.7
Stenonema reesi			2.4	1.0	2.6	1.2	2.0	6.0
Rhithrogena sp.				.1	3.9		2.0	
Ephemerella sp.			2.4	2.1	3.9	3.6	5.9	3.0
Tricorythodes sp.							3.9	
Tricorythodes minutus		.8	3.6	3.0	2.6			
ODONATA								
Ophiogomphus morrisoni			1.6	.8		2.4	2.0	
Argia sp.		.8						
PLECOPTERA								
Brachyptera sp.	1.0	1.7	13.0	21.6	18.4		3.9	1.5
Leuctra sp.		.8	4.5	5.6	6.6			
Capnia limata					5.3			

(Table II cont. next page)

TABLE II (Continued)

	HOSFORD I	HOSFORD II	BIRNEY I	BIRNEY II	ASHLAND	VIALL	S & H	T & Y
Isogenus modestus					1.3	1.2		
Isogenus frontalis						1.2		
Acroneuria abnormis			2.4	2.5	1.3	2.4		
LEPIDOPTERA								
Cataclysta sp. (Paragyractis)			.4	.6				
TRICHOPTERA								
Cheumatopsyche sp.			15.0	9.3	6.6	26.5	25.5	64.4
Hydropsyche bifida			13.4	9.2	11.8	14.5	11.8	3.0
Hydropsyche sp. a	19.4	4.2	6.1	14.4	6.6	13.3		
Hydropsyche sp. b	2.0	.8		.1	1.3	3.6	3.9	
Hydropsyche sp. c	23.5	8.4	8.1	8.4	1.3	18.1		
Hydropsyche sp. d			2.0	.4				
Brachycentrus numerosus				.3				3.7
Brachycentrus americanus					1.3	2.4	11.8	3.7
Athripsodes sp.			2.4	2.2	2.6			1.5
Leptocella sp.	2.0		4.1	.3				
Limnophilidae (cases only)	1.0							3.0

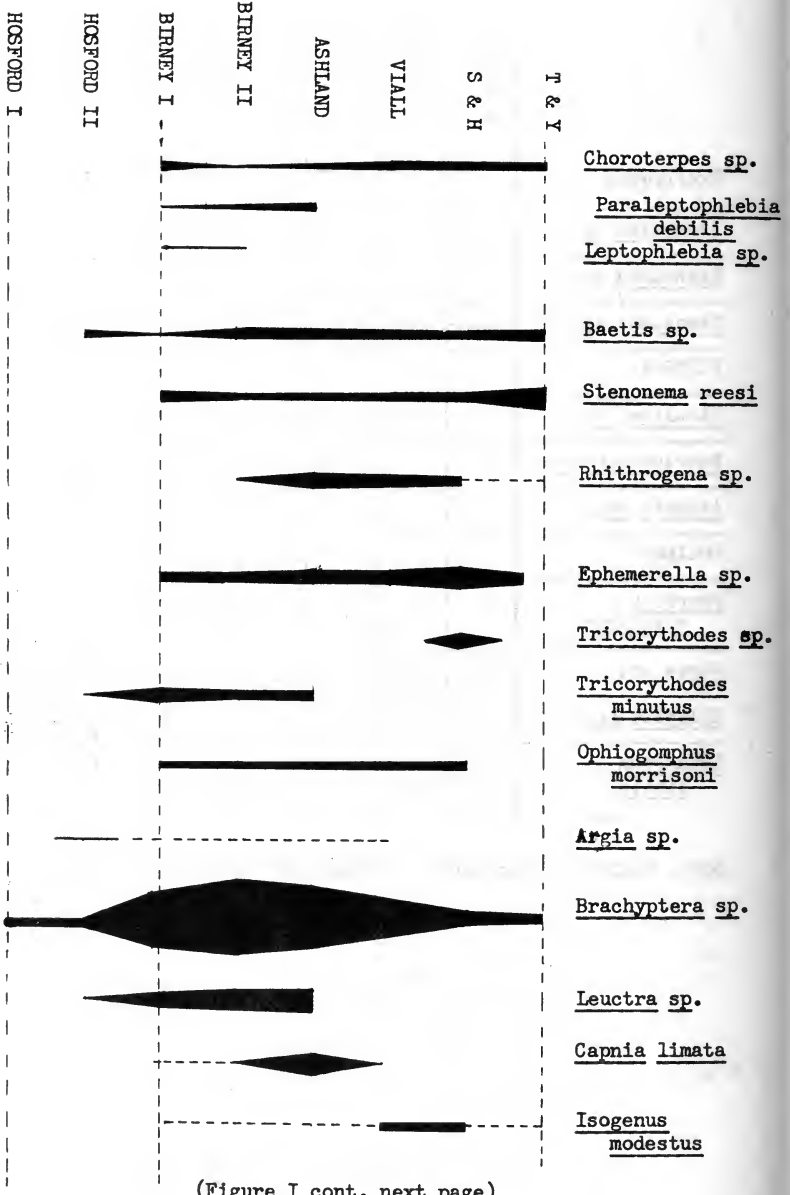
(Table II cont. next page)

TABLE II (Continued)

	HOSFORD I	HOSFORD II	BIRNEY I	BIRNEY II	ASHLAND	VIALL	S. & H	T & Y
COLEOPTERA								
Laccobius sp.								.8
Stenelmis sp. a			5.7	3.1	1.3	7.2	7.8	3.0
Stenelmis sp. b	12.2	20.2	5.3	7.5	2.6			
DIPTERA								
Simulium sp.		12.6	.4	.3			15.7	1.5
Metriocnemus sp.			4.1	2.5	4.0			
Atherix sp.				.4	10.5			
MOLLUSCA								
Ferrisia rivularis		.8			1.3			
Physa sp.	15.3	31.9						
Elliptio sp.							2.0	
Sphaerium simile	23.5	14.3						

NOTE: (Relative abundance in percent of total numbers per sample)

FIGURE I



The following kite diagram represents the relative abundance of the listed organisms (where 7.5 mm. of vertical distance represents 20% of the total population at that point) as well as the longitudinal distribution along the length of the Tongue River. The sample collection points are included as reference points to be used with the included map. The dotted vertical lines represent the boundaries of the cold water and warm water habitats as described in the text.

(Figure I cont. next page)

FIGURE I (Continued)

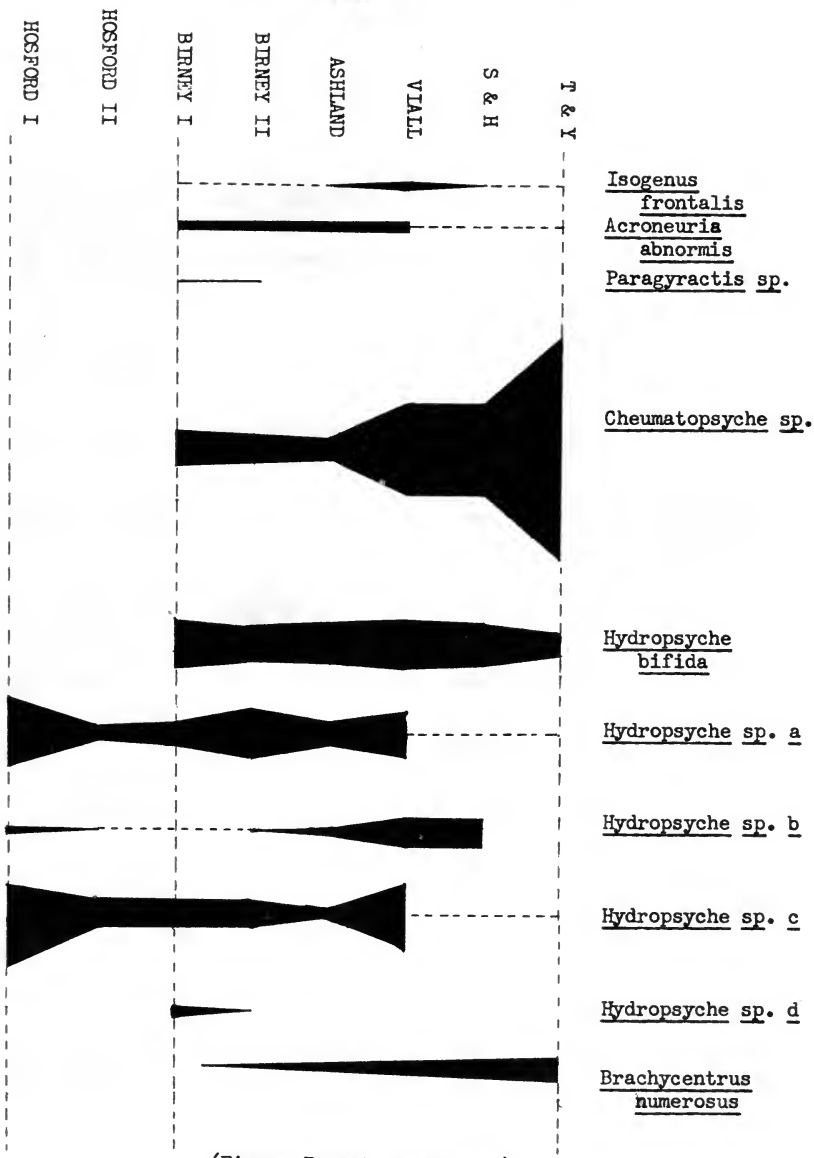


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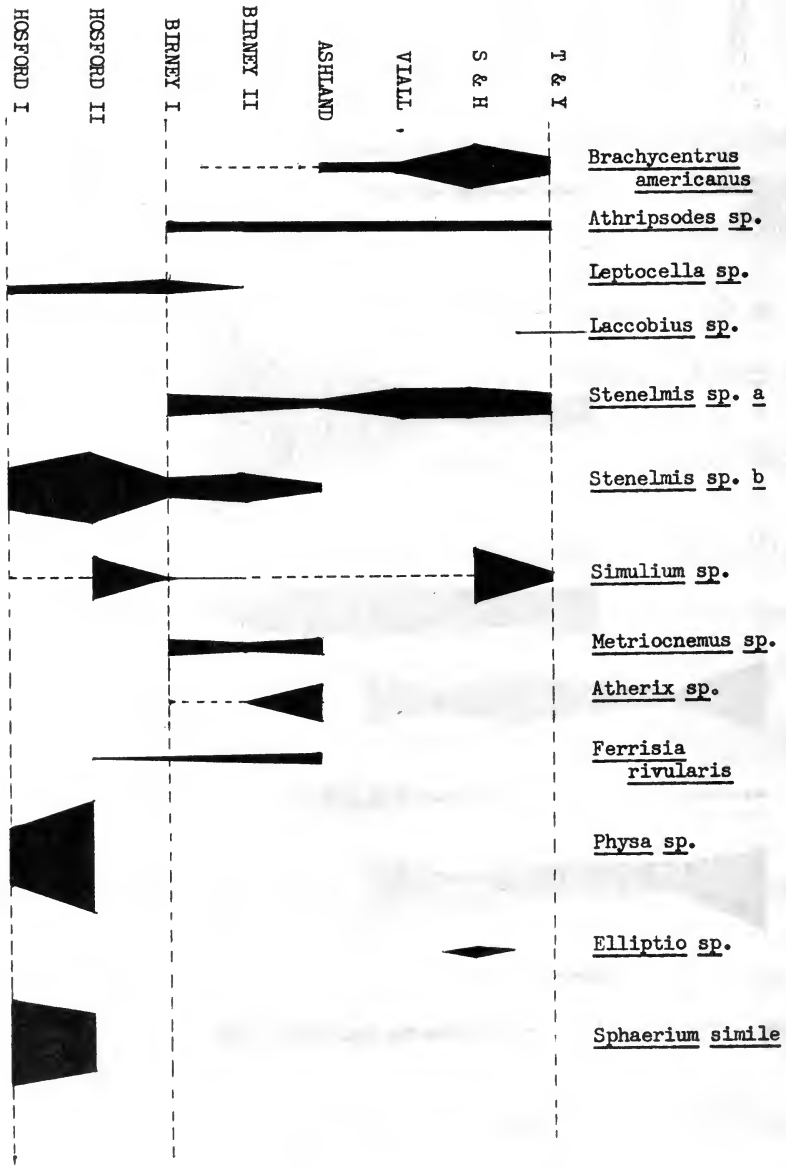
FIGURE I (Continued)



Most organisms live best in a situation of thermal flux which synchronizes the life cycle and stimulates growth of insect instars. Additionally, Lemkuhl (13) has found that diapause eggs, which require temperature fluctuations to hatch, will not hatch in areas influenced by hypolimnial release. Spence and Hynes (19) have also found that lowered temperatures cause the increase in growth and abundance of periphyton which leads to a radical alteration of the substrate, eliminating many substrate specific organisms.

Pearson, Kramer, Franklin (17) and Ward (21) found that with increasing distance from the dam, atmospheric conditions and tributary waters combine to return the river to its pre-impoundment state and the numbers of invertebrate species increases.

The Tongue River Reservoir dam has a hypolimnial release and the biological situations described above are exhibited quite distinctly on the Tongue River.

Thus, it can be seen that in the area of the river affected by the hypolimnial release, the insect fauna is diminished and the dominant forms are the molluscs *Physa* and *Sphaerium*. From the collection point data (Table I), the cold water area is also an area of light turbidity and increased periphyton as exemplified by the dense mats of *Cladophora*. Where the original temperature regime is re-established (in the Birney area) the increase of insect species is quite noticeable.

Either because the higher summer temperatures are not conducive to molluscan growth or the insects are better able to utilize the available resources, *Physa* and *Sphaerium* are diminished or eliminated and the dominant forms are the *Hydropsychids* and *Brachyptera*. The algal cover of *Cladophora* is reduced and *Nostoc* is present. Finally, as the river nears its junction with the Yellowstone River, a third community presents itself. Increased turbidity causes the amount of available light to be reduced and abrassive action of suspended particles fouls many insect gills or causes alteration of the substrate to other than optimum conditions (11). Thus, in the area of the lower river, where turbidity is high, the benthic fauna is dominated by *Cheumatopsyche* which can take advantage of the suspended matter in its feeding habits. The dominant form in this area, again being able to take advantage of less than optimum light conditions, is *Nostoc*.

ACKNOWLEDGEMENTS

The author is grateful to Dr. Andrew L. Sheldon for his help in identification of many of the invertebrate species and his critical review of this paper and to Mr. Ken Bovee for his technical assistance and suggestions. This study is supported by Environmental Protection Agency contract #68-01-2653 to Dr. Arnold Silverman.

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A STUDY OF THE IMPACTS OF REDUCED STREAMFLOWS IN THE MIDDLE AND LOWER YELLOWSTONE BASIN

Bob Anderson*

INTRODUCTION

If implemented, massive coal development in the Fort Union region will result in the diversion and consumption of large quantities of water (2, 9, 14, 15, 17, 19, 20, 21). A limited amount of surface water is available in the Yellowstone River Basin without construction of additional storage. With or without creation of further storage and regulation, such water development will cause major social, economic, and environmental impacts (7). The decision-making process has been hampered by ignorance of the nature and magnitude of many of these impacts.

On March 11, 1974, the Yellowstone Water Moratorium (12) was enacted. Prohibited for a three-year period were diversions greater than 20 cubic feet per second (14,480 acre-feet per year) and impoundments larger than 14,000 acre-feet. The moratorium gives the State of Montana an opportunity to seek answers to many impact questions. These answers should lead to more rational decisions.

A major environmental and economic impact study is being administered by the Montana Department of Natural Resources and Conservation. Funded by the Old West Regional Commission, this investigation will attempt to "evaluate potential physical, biological and water use impacts of water withdrawls and water development on the middle and lower portions of the Yellowstone River drainage in the State of Montana (16)." Referred to as "The Old West Study," this project is an impact "study," which may be contrasted with an impact "statement." Emphasis here will be on content and results rather than on compliance with guidelines and laws as in the case of an impact statement.

The project began on June 25, 1974 and is due for completion June 30, 1976. At this time, few results of the investigation are available. The purpose of this paper is to describe the plan of study and some of the questions being addressed.

OBJECTIVES

In addition to the broad objective quoted above, the project has three sub-objectives (16):

1. To refine, calibrate, and evaluate a surface water flow model for the middle and lower portion of the Yellowstone River Basin, with attention to the model's utility as a regional prototype.

2. To acquire data which relates the surface flow parameters of the water model to impacts on selected water uses. These water uses will be described in the section on research

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tasks, below.

3. To quantify, insofar as possible, the economic values and costs of various degrees of water consumption, with attention to conflicts and tradeoffs associated with foreseeable water use configurations.

PLAN OF STUDY

Figure 1 displays the plan of study and the way in which information will flow among the study team members. All of the activities shown in the boxes at the left of the figure began simultaneously and are ongoing.

The State Water Planning Model, developed by Boyd et al. (4), is being calibrated and verified in eight subbasins. This model will simulate yearly and monthly stream flows. A model developed by the U.S. Army Corps of Engineers (1) called Streamflow Synthesis and Reservoir Regulation (SSARR) is also being applied in selected stream reaches. The SSARR model has the capability of simulating fractional-day stream flow values.

Concurrently, several scenarios of possible future development conditions are being formulated. Each scenario is a unique combination of industrial and agricultural development. The extreme cases of no further development and maximum development are included. Basic to each scenario is a set of water allocations with priorities and a set of water supply schemes with storage sites and diversion points.

Flow conditions resulting from each scenario will be predicted by simulating flows with the models using the appropriate assumptions. The result will be the set of future flow configurations represented on Figure 1.

Throughout the study, field researchers will collect data on subjects discussed in the following section and formulate and test hypotheses which will lead to impact functions-relationships, as quantitative as possible, between stream flows and environmental variables. Depending on the quality of the data and the state-of-the-art of analytical techniques, impact functions may be: explicit, as implied on Figure 1; implicit, with ranges or envelopes of impacts predicted; or qualitative. The dependent variable of the impact function may have such units as visitor days/year, mg/l, or organisms/mile.

Combining the impact functions with the set of future flow conditions will provide a set of environmental impacts predicted to result from the stream flows associated with each scenario.

The type of data collected by field researchers will be influenced by the needs of the economic analysis. Conversely, the development and selection of economic methodologies are affected by the information supplied by the field researchers.

The final step of the process will be the union of the economic methodologies with the predicted impacts, resulting in sets of values which can be expected from the various scenarios. For example, large scale development may reduce the size of the

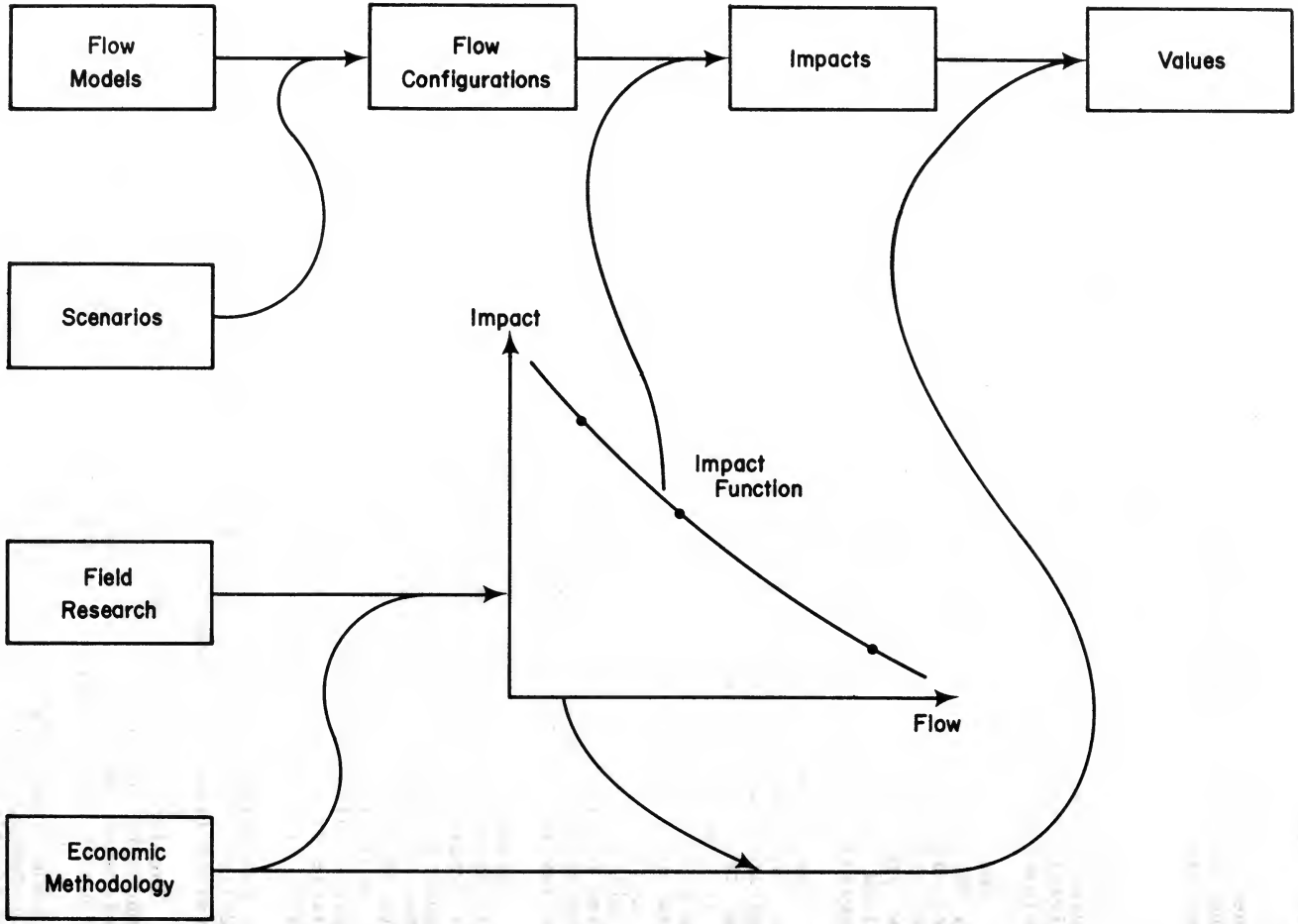

Figure I. INFORMATION FLOW AND PLAN OF STUDY

beaver population; the economic loss to trappers from this impact will be estimated. Dollar values will be provided to the extent possible. Necessarily, however, many of these values will be qualitative.

RESEARCH TASKS

Several of the areas of specific research are being performed through contracts with other agencies or organizations.

The Montana Department of Fish and Game is responsible for the following tasks:

1. Investigation of aquatic communities with particular emphasis on the habitats of the Tongue River Basin (6, 13, 18). The life histories of aquatic invertebrates and forage fish will be inventoried and studied.

2. Assessment of the impact of altered stream flows on selected migratory birds (8). The productivity and importance of the river, its islands, and its riparian vegetation will be determined for such birds as geese, ducks, bald eagles, and great blue herons.

3. Analysis of the impact of reduced stream flows on selected furbearing mammals. The habitats of beaver, muskrat, mink, river otter, and other furbearers will be studied in conjunction with population inventories.

4. Investigation of water-based recreation. Current and potential recreation use will be inventoried and analyzed.

The Water Quality Bureau, Montana Department of Health and Environmental Sciences, is responsible for analyzing the impact of altered stream flows on water quality. Sampling and analysis will complement programs of other agencies, particularly the U.S. Geological Survey.

The University of Montana is under contract to establish a vigil site network. This program will provide baseline data for future correlations of changes in channel geomorphology with events in the watershed.

All other tasks are conducted by the Water Resources Division of the Montana Department of Natural Resources and Conservation (DNRC).

One of the industries most sensitive to hydrologic changes is irrigated agriculture. Irrigated and irrigable lands have been identified and inventoried. The costs of supplying water to irrigable lands are being estimated. The feasibilities for development of each potential project will be predicted by comparing costs with farm income under a variety of market conditions and cropping patterns. Ultimately, future water use by irrigated agriculture will be estimated.

Often critical to irrigators and other diverters is the stage of the river. Water in the channel may be of little use if its elevation is below that of the diversion structure or

pump intake. DNRC is surveying river cross sections and will apply the Water Surface Profile program of the U.S. Bureau of Reclamation (5) to predict the water surface elevations at varying flows at a number of critical sites.

Of interest to the people of eastern Montana is the future availability of water for municipalities and non-energy industry. Municipal water demand is a function of population, which will in turn be dependent on the level of energy development. DNRC is estimating future populations by examining the future development scenarios. The ability of the river to supply the resulting water demands will be studied under a number of water development alternatives.

Coal-related water development can reduce stream flows throughout the year by relatively steady diversions or by reducing peak flows through storage of spring runoff. Either way, there will surely be changes in channel geomorphology (3). Erosion, transport, and deposition of sediment will be altered, possibly affecting many uses of the river. In cooperation with the University of Montana contractors, DNRC will attempt to predict some of these channel changes.

APPLICATION

One of the promising aspects of this research is its potential for immediate and effective application. The results of the project will be synthesized into the DNRC planning process which will produce the Yellowstone portion of the State Water Plan (10) for the 1977 legislature and for the Board of Natural Resources and Conservation. The Board was empowered by the 1973 Water Use Act (11) to reserve waters to provide for future beneficial uses or to maintain minimum stream flows.

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